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PROTEIN IN POULTRY NUTRITION[1]

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INTRODUCTION

Both from an economic and a physiological standpoint the protein fraction of the poultry ration is of major importance. Growing birds require large quantities of protein for the formation of muscle tissue, skin, blood solids, feathers and toe nails. Laying hens, although their requirements for growth are less, must have sufficient to meet the heavy demands of egg production. Moreover, every living cell in the body contains vital structures which require protein for their formation and maintenance. For all these needs the bird is dependent on a continuous supply of suitable protein from the diet since apparently it possesses little capacity for accumulating a reserve.

Workers in the field of nutrition are familiar with the fact that the proteins are built up of units of amino acids. Also familiar is the concept of the enzymatic breakdown of the complex protein molecules to their constituent amino acids during the process of digestion and the transport of these amino acids to various parts of the body where they are utilized for the formation of protein tissue. However, it is worth emphasizing that the amino acid requirement of an animal or bird is not merely quantitative but includes a demand for adequate amounts of several specific amino acids. It is evident that the ability of a protein to satisfy this demand determines its feeding value.

The amino acids which have been identified as occurring in natural proteins are listed below. On the basis of feeding experiments with rats, ten of these are classed as "nutritionally essential" i.e., they cannot be synthesized in the body of the rat and must be supplied through the nutriment to maintain normal growth. While it does not necessarily follow that the amino acid requirement of poultry is analogous to that of the rat, the experimental evidence available indicates that the requirement of poultry is at least as specific.

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Nutritionally non-essential	*Nutritionally essential*
Alanine	Arginine
Aspartic acid	Histidine
Citrulline	Isoleucine
Cystine	Leucine
Glutamic acid	Lysine
Glycine	Methionine
Hydroxy glutamic acid	Phenylalanine
Hydroxy proline	Threonine
Norleucine	Tryptophane
Proline	Valine
Serine	
Tyrosine	

In reviewing this field of poultry research, the author was impressed by the large volume of literature on the subject but encountered great difficulty in envaluating much of the work owing to the great diversity of conditions under which the experiments of the various investigators were carried out. Obviously, for example, to say that, during early rapid growth, the chick requires a level of 18 to 20% protein in its diet does not convey a very complete picture of the problems involved in satisfying this requirement. The source of that protein, any pretreatment to which it may have been subjected and its digestibility must be considered. Lack of adequate knowledge in regard to the amino acid requirement of poultry and the amino acid composition of protein feeds has handicapped workers in this field. Also it should be remembered that prior to about 1932 the importance of riboflavin in poultry rations for growth and hatchability was not generally recognized, and much of the early work on proteins may have been complicated by the ability of the protein supplement to supply this vitamin to the diet. These and other considerations will be mentioned later in this review.

Heuser (114) has published an excellent survey on the protein problem in poultry nutrition and Almquist (19) has discussed the amino acid requirements of chicks. The author has depended on these publications for guidance during the preparation of a considerable portion of this review.

1. PROTEIN REQUIREMENT FOR GROWTH

The protein requirement of the chick is most commonly measured by rate of gain in weight, but other factors such as efficiency of feed utilization, age of sexual maturity, feathering and general health of the birds are also considered.

Since the chick is a rapidly growing animal, doubling its birth weight in about 10 days, it is to be expected that the protein requirement of the chick during the early stages of its growth would be comparatively high. The results obtained by investigators in this field confirm this conclusion. Musseh1 (170), St. John *et al.* (210), Milne (161), Roberts and Carrick (201), Ackerson *et al.* (5), and Tomhave (250) observed that growth was stimulated during the first few weeks following hatching by protein levels up to 20% or over. Swift, *et al.* (234) fed various levels of protein to White Leghorn chicks

from the age of 2 weeks to 18 weeks and found that the greatest gains in weight were obtained with a level of approximately 21%. Winter *et al.* (266), in a study of the protein requirement of White Leghorn pullets between 6 weeks of age and the onset of laying, found that a drastic reduction of protein, especially at an early age, retarded growth and lowered the intensity of subsequent egg production.

The influence of the protein level of the diet, from hatching time to 20 weeks or longer, has been studied by many workers, the majority of whom agree that the early rate of growth of chicks increases with the protein level of the ration to an optimum of approximately 18 to 20% and that this level can be decreased as the birds mature.

Heuser and Norris (111) from their investigations at Cornell, concluded that the ration should contain approximately 20% of protein for the first 6 to 8 weeks, 18% from then on up to 12 to 14 weeks, and 15 to 16% for the rest of the growing period. Their data also showed that depressed growth in the earlier periods, provided it is not too severe, can be compensated later on by more rapid growth if the protein level becomes adequate. This latter observation was confirmed by the work of Carver *et al.* (64). The results of all trials at Cornell were summarized by Heuser (114), who stated that to obtain early rapid growth the ration should contain approximately 20% protein during the first month, and that this can be reduced 2% for each succeeding month to a minimum of not less than 15%.

The conclusions reached at Cornell were well substantiated at the Delaware Station by Tomhave (251). Using White Leghorn pullets and varying the protein level of the rations by changing the proportions of meat scrap and dried buttermilk, Tomhave made the following observations:

1. Lowering the protein level below 18% previous to 8 weeks of age resulted in lower weight of pullets at 20 weeks.

2. A protein level of 14 to 16% in the growing ration did not develop chicks as rapidly as they are capable of developing in the early growing period.

3. After pullets reached 8 to 10 weeks of age a 16% level of protein produced gains practically equal to a ration containing 18%.

4. During the first 8 weeks of the growing period an 18% level of protein produced a pound of gain on less feed than a 16 or 14% level.

5. The lowest feed requirement to make a pound of gain occurred when the growing ration contained 18% protein for the first 8 weeks and 16% from the 9th to at least the 16th week of the growing period.

Carver *et al.* (64) on the basis ofexperiments in which they adjusted the protein levels of their rations by varying the proportions of Alaska herring meal and dried whey, recommended that the chick diet should contain approximately a level of 17% high quality protein from 1 to 6 weeks, 15% from 7 to 12 weeks, and 13% from 13 weeks to maturity.

In experiments conducted by the United States Department of Agriculture (Hammond *et al.* (94)), groups of crossbred male chicks were fed for their full growing period on diets containing protein levels of 13 to 25% by increments of 2%. A percentage of 21% was found to be near the optimum for efficiency of food utilization. Titus (245) in reference to these results stated that although the optimum protein intake is from a physiological standpoint about 21%, from the standpoint of economy it may be only 18 or 19% because the efficiency of feed utilization for growth is only slightly less at these levels than it is at the 21% level. He recommended the feeding of a diet which contains 20 to 21% protein until the chickens are about 12 weeks old and than to a gradual decrease in protein content to about 16 or 17% by the time the pullets are ready to lay.

Further confirmation that a lower level of protein is adequate for the advanced growing period was provided by Dearstyne *et al.* (71) who found that 15% protein in the mash (grain fed in addition) was satisfactory for Rhode Island Reds from the time they weighed 1.5 to 2 pounds until production reached a level of 25 eggs per 100 birds per week.

It was observed by many workers (McConachie (157), Norris and Heuser (175), Swift *et al.* (234), Carver *et al.* (64), Hammond *et al.* (94)) that when growing chickens were fed varying amounts of protein, those fed high levels used the protein less efficiently and the feed as a whole more efficiently than chickens fed low levels of protein. It has been mentioned previously that depressed growth in the earlier periods due to relatively low level of protein intake may be compensated for later on if the protein level becomes adequate. Consequently, both low and high protein groups may eventually reach the same weight at maturity, and it would appear that little advantage would be gained by feeding a high protein level when the chicks are carried through their full growing period. However, it is quite possible that the more efficient utilization of high protein rations would more than compensate for their higher cost provided the price differential between the low and high protein ration was not too large. This is an important consideration from the standpoint of economy of feeding and it is unfortunate that in most of the feeding experiments recorded in the literature this factor has apparently not been considered.

There is conflicting evidence regarding the influence of the protein level of the ration on the age at which pullets begin to lay. Carver *et al.* (62) claimed that the rate of sexual maturity was retarded by a ration containing 12% protein and Carver *et al.* (64) noted that White Leghorn pullets fed rations containing 19% protein reached sexual maturity a few days earlier than those fed on rations containing 13%. However, the results obtained by other workers (Winter *et al.* (266), Dearstyne *et al.* (71), Byerly *et al.* (49), Morris (168), Tepper *et al.* (238), Heuser and Norris (112), Callenbach *et al.* (55)) indicated that the rate of sexual maturity was not influenced to any marked degree by the protein content of the diet. In view of this, it seems safe to conclude that the rate of sexual maturity cannot be hastened materially by a high level of protein in the diet and is only influenced by a level low enough to seriously delay growth.

As mentioned before, feather development is a factor to be considered in the protein requirement of the chick. Since feathers are composed chiefly of protein it is probable that poor feathering would result from an inadequate supply of protein in the diet. Tomhave (251) showed that when the protein level of the diet was reduced below 18% previous to 8 weeks, bare breasts occurred in White Leghorn pullets. Gericke and Platt (82), Ackerson *et al.* (5), and McConachie *et al.* (157) all reported feather development to improve proportionally with increased amounts of protein in the ration. The latter workers, using Barred Plymouth Rocks, found that this relationship was more marked in the cockerels than in the pullets. They also noted a high incidence of "crow's head" among the low protein diets. Margolf (152) noticed feather pulling, tail picking, and cannibalism developing among chicks on low protein diets as early as the second and third weeks. It is particularly interesting that McConachie *et al.* (157) observed that both high and low protein diets tended to destroy the barring and to change the contour and texture of the feathers. These effects were particularly evident on the high protein diets and with pullets. Possibly, the disturbance of normal barring was related to the tyrosine or phenylalanine intake of the birds.

As already indicated, there is general agreement that 18 to 20% is the optimum level of protein during the first few weeks of growth. A few workers, however, have found a higher level to be satisfactory. McConachie *et al.* (157) using a protein supplement of fish meal and buttermilk powder found a 25% level of protein to be optimum for growth during the first 6 weeks. Milne (161) obtained the most rapid and economical gains during the early growth period with a level of 23.3% Both Milne and McConachie *et al.* reported detrimental effects on growth rate when the protein level of the diet was raised to 30% or over and the latter found a high mortality among chicks at a 35% level. It appears, however, that the highest levels most generally recommended (18 to 21%) can be fed without detrimental effects. Carver *et al.* (62) conducted a post-mortem examination of chicks fed from hatching to 38 weeks on a ration containing 18.2% protein and found no injury to the heart, liver, spleen and kidneys of the birds.

The influence of the breed on protein requirement has received little study. Most workers have used White Leghorn chicks as experimental birds. There is some evidence, however, that the requirement for the heavier breed chick is somewhat higher. Investigations carried out in Australia (20) showed that heavy breeds such as Light Sussex and Australorp made the most satisfactory gains when a high protein ration (18 to 19%) was carried to 9 weeks of age. White Leghorns, on the other hand, did equally well when the protein level was reduced to 14 or 15% at 6 weeks.

Mitchell *et al.* (163, 165) studied growth changes in White Plymouth Rock and White Leghorn chicks by chemical analyses of birds slaughtered at regular intervals. Using the results of these analyses, they compiled a table of tentative feeding standards, part of which is given in Table 1. The values for maintenance were obtained by Mitchell and cooperators by reference to the work of Ackerson *et al.* (1) on the endogenous metabolism of hens and capons.

TABLE 1.—ESTIMATED DAILY CRUDE PROTEIN REQUIREMENT OF GROWING WHITE LEGHORN AND WHITE PLYMOUTH ROCK CHICKENS[1]

Body Wt.	White Leghorns							
	Cockerels				Pullets			
	Maintenance	Growth	Total[2]	Dig. protein[3]	Maintenance	Growth	Total	Dig. protein
lb.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.
0.5	0.5	2.2	2.7	5.4	0.5	1.7	2.2	4.4
1	1.0	2.5	3.5	7.0	1.0	2.2	3.2	6.4
1.5	1.5	2.6	4.1	8.2	1.5	2.3	3.8	7.6
2	2.0	2.6	4.6	9.2	2.0	2.1	4.1	8.2
3	2.8	2.5	5.3	10.6	2.8	1.0	3.8	7.6
4	3.6	2.1	5.7	11.4	1.4	0.4	1.8	3.6
5	2.5	2.0	4.5	9.0				

Body Wt.	White Plymouth Rocks							
	Cockerels				Pullets			
	Maintenance	Growth	Total[2]	Dig. protein[3]	Maintenance	Growth	Total	Dig. protein
lb.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.
0.5	0.5	1.6	2.1	4.2	0.5	1.5	2.0	4.0
1.5	1.6	3.7	5.3	10.6	1.6	3.7	5.3	10.6
2.5	2.5	6.2	8.7	17.4	2.5	3.0	5.5	11.0
3.5	3.5	4.3	7.8	15.6	3.5	3.4	6.9	13.8
4.5	4.5	4.3	8.8	17.6	4.4	2.7	7.1	14.2
5.5	5.4	3.7	9.1	18.2	4.3	1.3	5.6	11.2

[1] Data of Mitchell, Card and Hamilton and Ackerson, Blish and Musselil.
[2] Total minimum requirement of protein.
[3] Assuming a biological value of 50.

The protein requirement for most rapid and economical gains during the full growing period may be summarized as follows. During the first 4 to 6 weeks when the most rapid growth is taking place, the diet should contain at least 20% of protein of good quality. From the end of this period until the end of the growing period the level may be reduced gradually to a minimum of approximately 15%. Although a very high protein content of the diet (30% or above) results in high mortality among chicks, the highest levels most generally recommended can be fed without harm.

The considerable variation shown in the results obtained by different investigators can probably be attributed to variations in climatic condition, management and strains or breeds of birds used. Moreover, there is no doubt that the optimum level varies with the biological value of the protein. It should also be remembered that changes in other components as well as the protein are involved when the protein level is adjusted by changing the proportion of the concentrate. Consequently, one cannot always be certain that the observed results can be attributed solely to a change in the protein level of the ration.

2. PROTEIN REQUIREMENT FOR EGG PRODUCTION

The value of a ration for laying hens should be based on a consideration of egg production, egg size, body weight, efficiency of food utilization, and general health and well being of the birds.

The average hen's egg contains approximately 14.0% protein which, according to Wilcox (261) is practically all drawn directly from the nitrogen of the food. However, Ackerson *et al.* (2), in the course of nitrogen metabolism studies with poultry found that hens laid eggs 6 to 7 days after the nitrogen intake had been reduced to a neglible amount. Apparently, there must be some labile protein stored in the hen's body which she can utilize for the production of eggs for a limited period.

Bird and Sinclair (38), in a study of the energy requirement for maintenance and egg production, found that 63% of the food which was available for egg production was utilized for this purpose, except at the start of laying when the efficiency was somewhat higher. Muller-Lenhartz and Von Wendt (169), assuming that 64% of the digestible protein is utilized, estimated that the ration of the laying hen in average production should contain 185 grams of digestible protein per kilogram of egg. With ad libitum feeding of a protein concentrate, there seems to be a tendency for the hen to adjust her protein intake to a characteristic level. Trials at the Ohio station (Kennard and Chamberlin (133)), have shown that on a free choice method of feeding (mash and grain) the hen balanced her ration at a protein level of approximately 15%. Graham (84) found that when pullets were fed ad libitum whole corn, whole oats, and mash, the variation in protein level for individual birds was very slight. Some birds laid well and gained on a 12 to 13% level, while others desired or required 14 to 15%. Where the protein requirement was high, however, egg yield was not necessarily high also. Rhodes *et al.* (196) showed that laying pullets, fed on mashes, low, medium and high in protein, had a tendency to adjust the level of protein intake to a common level by varying the relative amounts of mash and grain consumed.

Reports from several experiment stations indicated that a medium level of protein in the diet promoted satisfactory egg production. From Cornell, Heuser (113) reported that probably a 16% protein level in the ration is near the optimum for laying hens. With casein as a supplementary protein, 16% protein gave satisfactory egg production, body weight and egg size, 14% protein gave satisfactory egg production but did not maintain body weight or optimum egg size, and 12% protein proved completely unsatisfactory. This work was largely substantiated at the Washington station by Heiman *et al.* (106) who concluded that a laying ration fed at a level of 15% protein from adequate sources (plant and animal) can safely be recommended for satisfactory egg production. These workers found that a 12 to 13% level of protein from plant sources alone was inadequate. Thompson (241) reported from the New Jersey station that trials with laying rations containing 10, 12, and 14 and 16% protein indicated a 14% level as the most efficient, and he concluded that a fairly high level of protein is necessary to maintain body weight and stimulate egg production.

The results of experiments conducted in Germany (Zollner (268), Weinmuller *et al.* (257), Albrecht (7), Jaeger, *et al.* (121)), supported the finding of American workers that egg production is in accordance with protein level. Zollner (268) fed White Leghorn pullets 3 levels of protein, 9.6%, 13.8%, and 18.0%, and although the high protein lot showed the highest utilization of the food protein, the medium protein lot gave the best egg yield. Zollner also noticed an apparent connection between protein supply and moulting, the latter being lighter and shorter with the higher amounts of protein. Albrecht (7) using as a protein supplement a mixture of fish meal, soyabean meal and peas, reported that a nutritive ratio of 1 : 4.38 gave maximum egg yield and that a ratio of 1 : 11.85 was totally inadequate for egg production.

Several experiments have been reported from England. Investigations by Thomas (239) in which Rhode Island Red hens were kept 13 months on high, medium and low protein intake indicated that although more eggs were produced on the high level, the medium protein level gave the lowest food cost per egg. MacDonald (145) reported that for egg production 14.2% in a mash forming one-half the total diet was as satisfactory as 20.8% provided the birds were allowed outside range. On a later study, involving N balance experiments, MacDonald (146) noted that hens could be kept in positive N balance on a diet containing 12.5% protein and that this level compared favourably with 15.4% for egg production.

The question might arise concerning the influence of the level of protein fed during the growing period on subsequent egg production. Carver *et al.* (64) fed protein levels varying from 13 to 19% during the first 22 weeks from hatching and 15.3% thereafter and found that, during the first 224 days of egg production at least, the different diets fed during the growing period had no influence on the rate of egg production. Moreover, the average initial and final albumen index (Heimand and Carver (105)) and egg weights were not influenced by the amount of protein fed in the diet of the growing pullets. Bronkhorst (43) fed growing White Leghorn pullets levels of 10, 15 and 20% meat meal with a basal ration of yellow corn and wheat by-products and noted that the age of sexual maturity and subsequent egg yield did not seem to be affected by the different levels.

There seems to be some difference of opinion regarding the effect of the protein level of the ration on egg size. Lampman (139) observed that eggs from pullets receiving plenty of protein averaged 2 oz. per dozen, heavier than eggs from pullets on medium or low protein allowance. Bronkhorst (43), whose work was mentioned above, found that the size of egg was directly dependent on the level of meat meal in the ration. Heuser (113) and Heiman *et al.* (106), using casein and fish meal respectively as protein supplements, found that egg size increased as the protein level of the ration was increased to approximately 15 to 16%. These findings, on the other hand, are in disagreement with those of several other investigators. It was reported by Parkhurst (188) that varying amounts of protein in a ration, when the minerals content remained the same, did not have any significant effect on egg size. He also noted that a complex

protein was as ineffective as a simple one in increasing egg size. Similarly Graham (86) found no relationship between egg size and type of protein concentrate fed. He compared beef scrap, tankage and fish scrap, added on an equivalent protein basis to a basal mash, and buttermilk powder of which one-half the quantity by weight was used. It would appear from the results with the tankage supplement that, at least within certain limits, protein quality was not related to egg size. Henderson (108) observed a small but significant decrease in average annual weight of pullets with increased protein level in the ration. Two different protein supplements (dried milk and meat and bone meal) were used in adjusting the protein level of the ration from 12.3 to 14.9% and both had the same effect on egg weight. It was noted that this effect did not depend on annual egg yield, the number of eggs produced per month not being influenced by the percentage protein in the diet.

The protein requirements of several breeds of laying hens have been compared by Baelum (26). A light breed, Brown Italian, required 10.5 to 11% digestible true protein. This is provided by a daily ration of 65 gr. grain with free access to a mixture containing 16% of digestible true protein. The heavier breeds, Plymouth Rock, Rhode Island Red and Sussex, required slightly more total protein and so ate more of the protein mixture. No advantage was gained by feeding more protein than was provided in this way but egg yield fell in proportion as the supply fell short of this level.

There appears to be little information on the effects of feeding excess protein to laying hens. However, Miller and Bearse (160) found that a ration containing 30% of a protein concentrate did not produce a high percentage of organic trouble and Heuser (114) stated that, in general, experience has shown that hens can tolerate a fairly high protein ration if other conditions are favourable.

Although there is general agreement among workers regarding the protein requirement for egg production, there is a great need for a standardized procedure. Large group sizes and careful randomization in the distribution of individuals among the groups is very necessary in biological work. Henderson (109) in a critical survey of several methods for testing the influence of different rations on egg production suggested that: (1) yearling hens of previously determined egg laying ability when fed the same ration should be evenly distributed among the different experimental lots; (2) production should be calculated on the basis of the average number of egg per hen per day, and moulting and known broody and "sick" periods should be deducted from the number of days in which laying is considered possible; (3) the length of testing period may be a laying year or 12-month provided that the rations to be tested have been fed at least one month prior to the beginning of the laying year; and (4) that statistical methods should be used in interpreting the results of experiments.

3. PROTEIN REQUIREMENTS FOR HATCHABILITY

The problem of the nutrition of the breeding hen is of most practical importance during the winter months when, owing to snow and adverse weather conditions, the birds must remain inside and green feed and

beneficial sunlight are not available. While the quality and quantity of the protein in the diet of the hens is no doubt of great importance for hatchability, it is difficult to evalute the available evidence since in many cases the protein supplement may make up deficiencies, not only in proteins, but in vitamins and minerals as well. It is generally agreed upon, also, that genetic inheritance has a great influence on the successful hatching of a fertile egg. This is exemplified by the observations of Patton and Rouls (186) who found that, in a group of White Leghorn pullets of the same age and fed on a diet considered adequate in all respects, the hatchability of eggs from individuals ranged from 0 to 95.6%.

A level of approximately 16% protein of good quality has been recommended for egg production, and it appears that this level of protein is also satisfactory for hatchability. It was shown by Jull (127) that heavy egg production was not detrimental to, but rather was conducive to, high hatchability. Davis (70) suggested that the most practical means of solving the protein problem for breeding hens was to feed a ration containing from 14 to 16% of protein that was supplied from both animal and vegetable sources. Byerly *et al.* (50) found no correlation between the percentage of protein in the diet and hatchability. However, later, Titus (246) stated that, if the protein content of the diet were reduced sufficiently, the hatchability of the eggs was decreased and he recommended a diet containing 16% of protein of good quality.

A report from Germany (Muller-Lenhartz and Von Wendt (169)) indicated that a ration too high in protein had a detrimental effect on fertility and hatchability and that a satisfactory ration should contain approximately 185 grams of protein per kilogram of egg.

The relative value of animal and vegetable protein for breeding hens has been the object of several investigations. Hatano (116) found that animal protein instead of vegetable protein in the ration of the cock or the hens greatly increased the number of copulations per day. Byerly *et al.* (49, 50) observed that the substitution of vegetable protein for animal protein greatly increased the incidence of chondrodystrophy and caused the occurrence of a large number of dead germs in the second week of incubation. On the other hand, investigations in the author's laboratory (189) with sunflower seed oil meal showed that the partial substitution of animal protein in the ration with this product did not lower hatchability or result in a greater incidence of chondrodystrophy. Heiman *et al.* (106) noted that supplementing a basal ration of grain and alfalfa meal with fish meal gave increased hatchability. Albrecht (7), also from Germany, reported that hatchability was best when a ration high in plant protein was fed during the laying period.

Although the reports cited above are contradictory, the weight of evidence suggests that the ration should contain a considerable proportion of animal protein. It should be noted that a ration which gives high egg production is not necessarily satisfactory for hatchability. It is usually advantageous, when compounding a hatchability ration to include a protein supplement rich in riboflavin in order to ensure an adequate supply of this vitamin in the diet.

Our present knowledge is inadequate to explain the apparent relationship between the protein in a hen's diet and the hatchability of her eggs. Titus *et al.* (244) noted that the percentage protein in the yolks was increased by the inclusion of certain protein supplements in the diet. McFarlane *et al.* (158) found no significant difference in the composition of the protein of eggs of poor hatchability and those of high hatchability as far as the total N, total amino N, tyrosine, tryptophane and cystine content were concerned. There was no evidence that the diet of the hen significantly influenced these values. An investigation by Calvery and Titus (56) along similar lines also yielded more or less negative results. Undoubtedly, the general health of the birds is an important factor affecting hatchability, and possibly, as Heuser (110) stated, "the physiological condition of the hen is the important consideration and hatchability is influenced by the various factors as they in turn affect condition."

4. AMINO ACIDS IN POULTRY NUTRITION

The 10 amino acids classified by Rose (206) as "nutritionally essential" for normal growth in the rat have been listed in the introduction to this review.

Since, in general, it has been found that the dietary requirements of birds are more complex than those of the mammals, it may be expected that the amino acid requirement of the chick will be at least as specific as that of the rat. However, up to the present time, only a few amino acids have been studied in any detail relative to their importance in poultry nutrition, namely, methionine, cystine, glycine, arginine, tryptophane and lysine. The requirement of these amino acids for growth have been established only approximately and only for the White Leghorn breed. Obviously, much work remains to be done in this field. Apparently, there is no available information in the amino acid requirement of laying and breeding hens. It has been shown that the level of protein required for egg production and hatchability is lower than that necessary to support rapid growth. However, it may be well that the amino acid requirements for these purposes differ considerably and it would seem that there is presented here another fertile field for investigation provided certain technical difficulties can be surmounted.

The most fruitful investigations into the amino acid requirement of the rat have been conducted using mixtures of pure amino acids as the sole source of protein in the diet. So far this method has not been applied to chicks owing to the expense of the procedure and the rather complex dietary requirements of the chick which makes the formulation of such a highly purified diet difficult. However, valuable information has been secured by selecting protein combinations which are very low in their content but not necessarily free of the amino acids under study. Casein has been used as the "foundation" protein in most of these studies. It is interesting to note in connection with its use, that even the most favourably supplemented acid hydrolyzed casein diets were inferior to diets containing the unhydrolyzed casein for the promotion of growth (Klose *et al.* (136); Stokstad (232)). Apparently, whole casein contains some growth factor or factors, as yet unidentified, which are destroyed during acid hydrolysis.

In the following discussion of the amino acids known to be "essential" for the chick, the sulphur-bearing amino acids, cystine and methionine, have been grouped together since they are related in their functions. Similarly, glycine and arginine have been discussed under one heading.

Methionine and Cystine

Klose and Almquist (138) established the essential nature of methionine for the growth of chicks. Using a basal diet, containing 20% arachin, 5% gelatin, 5% brewers' yeast and 0.1% 1-tryptophane, they found the addition of at least 1.0% dl-methionine was necessary for optimum growth. Neither creatine, cystine nor homocystine could replace methionine although homocystine when combined with choline was effective. However, Jukes found that, although methionine could replace choline in the diet of the rat, it did not effect choline deficiency in the chicks and turkeys (124, 125).

It has been well demonstrated that the growing rat can synthesize cystine from the sulphur of methionine (Rose and Wood (207), Beach and White (33), Brown and Lewis (45)). The chick is undoubtedly similar to the rat in this respect. Hayward and Hafner (101) found that methionine was more effective than cystine for improving the growth of chicks fed raw soybean protein. Since such protein is low in cystine and suboptimal in methionine, it would appear that methionine can successfully replace cystine in the chick diet. Briggs *et al.* (42) found that chicks on a diet containing approximately 0.6% methionine required and could utilize at least 0.3% of cystine (or its equivalent of methionine) and concluded that, in diets suboptimal in methionine, cystine could supply about one-third of the total methionine requirement of the chick.

Glycine and Arginine

The chick differs from the growing rat in possessing a much greater dietary requirement for arginine (21) and a definite requirement for glycine (10, 11, 103, 12).

Klose *et al.* (136) estimated the arginine requirement at 1% or more of the diet. Apparently the Krebs-Henseleit mechanism for arginine formation and decomposition does not operate in the chick since ornithine, urea, or a combination of these, could not replace arginine (Klose *et al.* (136)). However, Klose and Almquist (137) found that citrulline could replace arginine in the diet of chicks and concluded that the chick was capable of converting citrulline into arginine.

Almquist *et al.* (12) estimated the glycine requirement to be about 1% of the diet. Larger amounts of glycine (2% or more) may be toxic to chicks (Almquist *et al.* (10)) and heavy daily doses of glycine (4 gm. or more) have proved fatal to hens (Patton (187)). It is not known whether the chick completely lacks the ability to synthesize glycine. Almquist and Mecchi (11) found that sodium and ammonium acetates could replace glycine for chick growth. It is probable that the chick is capable of a slow synthesis of glycine, the rate of which is insufficient to supply the requirement during early rapid growth.

A deficiency of either glycine or arginine results in poor growth, a tendency to low muscle creatine, poor feather development and a typical paralysis which is related to an organic lesion in the spinal cord. Hegsted *et al.* (104) described this paralysis as characterized by poor muscular development and a high stepping stilted gait with the hocks thrust forward and the toes extended. Arginine supplement when added to a ration deficient in both arginine and glycine, had some preventative action but glycine supplement alone had none. When both were fed together, however, complete prevention was obtained. Hegsted *et al.* (104) also noted that the glycine and arginine requirement for a rapidly feathering breed (Leghorns) was greater than for a slowly feathering breed (Plymouth Rocks) and concluded that the rate of feather formation was an important factor in determining the requirement of these two amino acids, particularly in view of the high arginine and glycine content of feathers. However, Jukes and Almquist (126) pointed out that imperfect feathering is a symptom observed with dietary deficiencies in general and may not in this case necessarily indicate a special requirement of arginine and glycine for the production of feathers.

Patton and Palmer (184) found that chick embryos with chondrodystrophy contained less glycine than normal embryos, probably as a result of poorer formation of cartilaginous and bony tissue, the proteins of which are especially rich in glycine. It was noted (Patton and Palmer (184), Patton (185)) that glycine was synthesized in the developing embryo. No relationship was found, however, between the occurrence of chondrodystrophy and the glycine content of the diet (Patton (185)).

The chick is similar to the rat in that glycine and arginine are involved in the synthesis of body creatine. This is evident from the fact that chicks on arginine and glycine deficient diets show an abnormally low muscle creatine which is raised by feeding both glycine and arginine (104, 15). Moreover, creatine supplements to arginine and glycine deficient diets lead to increased growth (15).

It has been well established by Bloch and Schoenheimer (40) that the main pathway for synthesis of creatine in the rat is a reaction of glycine with the amidine group of arginine to form guanidoacetic acid, and a methylation of the latter to form creatine by a shift of the methyl group from metionine. The evidence supports the belief that, although differing in a few respects, the pathway in chicks is essentially the same. Almquist *et al.* (15) found that guanidoacetic acid, creatine and creatinine were all effective in raising muscle creatine and promoting growth with chicks fed on diets low in glycine and arginine. It would appear from this, that creatinine formation in the chick is closely related to body growth and also that creatine can be reversibly transformed into creatinine. On the basis of experimental evidence, Almquist (19) proposed the following scheme for the biological formation of creatine in the chick:

$$\text{glycine} + \text{arginine} \rightarrow \text{glycocyamine} \ (+ \text{ornithine?})$$
$$\text{glycocyamine} + \text{methionine} \rightarrow \text{creatine} \ (+ \text{homocysteine?})$$
$$\text{creatine} \leftrightarrows \text{creatinine.}$$

It has not been proven that methionine is necessary in the above scheme. Methionine deficiency, serious enough to prevent growth, did not reduce the muscle creatine below normal (Almquist *et al.* (15)). Ornithine, if produced, could not be reformed into arginine (Klose *et al.* (136)) but methionine could possibly be replaced by a combination of the homocysteine and choline (Klose and Almquist (138)).

Other Amino Acids—Lysine, Tryptophane and Histidine

To study the requirement for lysine, Almquist and Mecchi (16) used a diet containing as the amino acid source 25% edestin, 1.0% glycine and 0.4% dl-methionine. Growth response on the addition of 1 l-(+)-lysine monohydrochloride indicated that for the highest rate of growth the diet should contain approximately 0.9% lysine.

Experiments by Almquist and Mecchi (14) indicated that the chick possesses a requirement for tryptophane. This has been estimated very approximately at 0.5% of the diet, a value which is 2.5 times the requirement suggested by Rose (206) as being adequate for the rat.

Klose *et al.* (136) observed that chicks fed on a diet low in histidine exhibited an increase in growth rate when this amino acid was supplied.

5. PROTEIN SUPPLEMENTS

The cereal basal diets which are commonly used in poultry rations and which supply the largest fraction of the protein in the diet are seriously deficient in several of the essential amino acids required by the chick. Therefore, the value of a protein supplement, as such, will depend on how well it can make good the deficiencies of the basal ration in these essential amino acids. Almquist (17) compiled amino acid data, obtained from many sources, for a large number of poultry feedstuffs. These values plus some more recent data published by Block and Bolling (28) are given in Table 2. It is obvious that this table can at best serve as only a rough guide to the amino acid composition of the various concentrates. Not only are the data very incomplete, but methods for the estimation of amino acids are still imperfect and in certain cases the results obtained by the various workers may not be strictly comparable. However, it should be realized that, although a more complete knowledge of the amino acid composition of the common poultry feeds and the amino acid requirements of poultry would greatly assist in making the most efficient use of protein supplies, such factors as palatability and digestibility will always make practical feeding trials a necessity. Moreover, in addition to contributing amino acids to the ration, protein supplements are often valuable sources of other important dietary factors, chiefly minerals and vitamins. Drastic replacement of animal protein concentrates by their vegetable counterparts may, in some instances, necessitate an addition of certain minerals in order to balance the diet. For example, Heuser *et al.* (115) found that rations in which the protein was supplied by cereals and 30% soybean meal were too low in available phosphorus to promote normal chick growth and bone development.

When the results of feeding trials are evaluated, the conditions under which the tests were conducted should be carefully considered and broad interpretations avoided. It is important to bear in mind that the composition of the basal ration used in the experiment may have a great influence on the supplementary value of the added protein concentrate. In addition, the biological value of the protein or the mineral and vitamin content of supplements of the same class, i.e. various meat products, various fish meals, etc., may differ greatly depending on their source or method of manufacture.

(a) *Meat and Bone By-Products*

Included under this classification are meat and blood meals, tankage, bone meal, and several other related products containing varying amounts of meat, fatty tissue, blood and bone. Data on the amino acid composition of the protein of a few meat by-products are given in Table 2. It appears that animal proteins tend to be rather low in tryptophane. It is worth noting that Mitchell and Smuts (166) found beef protein to be too low in cystine to give optimum growth in rats.

TABLE 2.—AMINO ACID COMPOSITION OF SOME PLANT AND ANIMAL PROTEINS[a]

Feedstuff	Percentage of Amino Acid in Protein						
	Arginine	Histidine	Lysine	Glycine	Methionine	Cystine	Tryptophane
Whole corn[b]	4.0	2.4	2.5	—	—	1.1	0.7
Corn gluten[b], commercial product	3.1	1.7	1.1	—	5.5	1.2	0.6
Wheat, winter, hard	2.4	0.8	7.6	—	—	1.1	0.9
Wheat bran, winter, hard	1.9	0.3	10.8	—	—	0.5	0.6
Wheat shorts, winter, hard	3.4	0.3	10.0	—	—	0.7	0.7
Wheat germ meal[b], commercial product	6.0	2.5	5.5	—	2	0.6	1.0
Cracklings	—	—	—	—	—	0.7	0.8
Sardine meal	6.5	1.2	6.8	—	4.6*	1.1	1.5
Whale meal	—	—	—	—	—	0.9	1.8
Menhaden meal[b]	5.9	2.4	5.7	—	3	1	1.2
Salmon meal	6.6	1.9	6.6	—	—	1.3	1.3
Tuna meal	—	—	—	—	3.6*	—	—
Dogfish meal	6.7	—	—	—	—	0.9	1.5
Gelatin	8.2	1.0	5.9	25.5	0.0	0.2	0.0
Hoof meal[b], commercial product	10.4	1	3.2	—	—	7.3	1.5
Tankage[b], commercial product	5.5	2.7	6.0	—	3	1	0.7
Meat scraps[b], commercial product	7.0	2.0	5.1	—	3	1.0	0.7
Casein, 85% of milk proteins	3.8	2.5	6.0	0.5	3.3	0.5	2.2
Lactalbumin, 14% of milk proteins	3.0	2.1	8.8	0.4	2.7	4.3	2.7
Milk proteins	3.6	2.4	6.3	0.5	3.2	1.0	2.3
Egg white, 38% of egg proteins	5.3	1.4	5.8	—	4.1	1.5	1.5
Egg yolk, 62% of egg proteins	7.8	1.3	5.2	1.0	—	1.5	1.3
Egg proteins	6.9	1.3	5.4	1.8	—	1.5	1.4
Yeast[b]	4.3	2.8	6.4	—	—	1.3	1.4
Soybean meal[b], commercial product	5.8	2.3	5.4	—	2.0	1	1.5
Cottonseed—Globulin, 33% of protein	11.7	3.2	5.4	1.2	3.2	1.1	1.4
Hempseed—Edestin, 50% of protein	15.8	2.2	2.2	3.8	2.3	1.0	1.5
Peanut—Arachin, 60% of protein	12.5	2.1	1.7	0.0	0.6	1.5	0.9
Alfalfa, leaf proteins	7.5	1.4	5.8	—	—	—	—

[a] Data compiled by Almquist unless otherwise indicated.
[b] Data of Block and Bolling.
* Determined biologically.

In general, the proteins of meat meals are of somewhat lower feeding value than those of fish meals, since the latter contain smaller proportions of connective tissue. Such tissue tends to be lower in protein value than muscle tissue (Mitchell *et al.* (164)). Inability to utilize the protein may be as important as amino acid composition in causing this low feeding value. It is interesting to note that wool, which in its natural state is highly resistant to peptic and tryptic digestion, was readily used by rats as a protein for growth when finely powdered (208). Similarly, Wagner and Elvehjem (254) found that powdered swine hoof was superior to purified casein as a protein supplement for growing chicks. On the other hand, Slinger *et al.* (224) found that powdered hoofs and horns obtained mostly from steers and cows were slightly inferior to meat meal in chick rations and definitely inferior to fish meal.

Tankage is not recommended for poultry rations. Most tankages contain considerable quantities of blood meal and "stick" which lower their nutritive value. Mussehl (171) found that blood meal fed to growing chicks was decidedly inferior to other animal products. Almquist and co-workers (8) obtained very poor growth when tankage was used in chick rations and Graham *et al.* (85) noted that, when tankage was used in place of either fish scrap or beef scrap in laying rations, both egg production and hatchability decreased considerably. The results of Graham and co-workers, however, were probably complicated by deficiencies of riboflavin in the rations used. Attempts to use urea as a protein supplement (Ackerson *et al.* (6); Bice and Dean (37)) showed that nitrogen of this compound was not utilized by young chicks as a source of protein.

There are contrary reports in the literature regarding the influence of meat products which have developed a high free fatty acid content. Kaupp (131) found that the feeding of fish meals of high free fatty acid content was deleterious to the growth and health of chicks. Te Hennepe (237) reported a decided difference in egg production between a group of birds fed a meat meal containing 19% fat analyzing 23% free fatty acid and another group fed meat meal containing 10% fat of which 7% was free fatty acid. His results, of course, could have been influenced by the difference in the amount of fat in the rations, although it is worth noting that Fangauf and Muller (76) found that meat meals of high fat content had no unfavourable effects when fed to laying hens.

Several investigators (Hunter *et al.* (118); Gutteridge (89); Halpin *et al.* (91); Branion *et al.* (41)) were unable to correlate the acidity of cod liver oil with the growth and livability of chicks, and concluded that fatty acids per se were not responsible for harmful effects which had followed from the use of certain poultry rations.

Schroeder *et al.* (214) observed a decrease in growth and feed consumption and a great increase in mortality when meat scraps high in free fatty acids were included in the ration. However, he attributed his results to an inactivation of vitamin A and to a lesser extent vitamin D by the free acids. On the other hand, Gray and Robinson (87) could find no evidence that very rancid fat had an appreciable effect on the vitamin A content of freshly mixed, well balanced rations. They noted that chicks,

fed on well balanced rations containing meat scraps varying in rancidity and in free fatty acid content (quite comparable in this respect to the meat scraps used by Schroeder *et al.* (214)) showed no significant difference in growth or mortality. It was suggested by Gray and Robinson (87) that deleterious effects observed by other workers may have been due to the presence in the meat products of toxic end products resulting from bacterial action prior to processing.

(b) Fish Meal

The general belief that fish meal is one of the most valuable of the protein supplements used in poultry rations and, in many cases, superior to meat meal is supported by the findings of many workers including, Johnson and Brazie (123), Mussehl (171), Mussehl and Ackerson (173), Arsenjew and Chlebnikow (22), Wiegner and Tscherniak (259, 260), Fangauf and Haensel (77), Robertson *et al.* (203, 204), and Carver *et al.* (63). Almquist *et al.* (9) reported that, unless the fat content is far above the average of 6 to 8%, fish meal, even when fed in large amounts, will give no taste or odour to the eggs or meat of birds to which it is fed. A contradiction to this, in the case of turkeys, will be discussed in a later section of this review.

The value of a fish meal product may depend greatly on the method of its manufacture. Daniel and McCollum (69), Schneider (213), Maynard *et al.* (154), and Maynard and Tunison (155) found that flame dried fish meals were inferior to either vacuum dried or steam dried for promoting growth in rats and concluded that the high temperatures to which the meals were exposed during the flame drying process lowered both the biological value and the digestibility of the proteins. Record *et al.* (194) and Wilgus *et al.* (262) reported similar findings with chickens although it should be mentioned that Cleveland and Fellers (67) could find no evidence that vacuum dried fish meal was superior to the flame dried product for growing chicks.

Meals manufactured from different species of fish or from different parts of the fish may differ considerably in their feeding value. Undoubtedly, fish meals prepared from whole fish or containing a large percentage of the more edible portions, will be of higher value than meals prepared from fish waste. Record and Bethke (193) in a study of the effect of several fish meals on the growth of chicks found that cod and haddock meals were superior to menhaden, shrimp, tuna, salmon, pilchard and crab. Chlebnikow and Arsenjew (65) found herring meal to be superior to cod meal. Asmundson and Biely (23) compared the rate of growth of chicks raised on rations supplemented with pilchard, salmon and halibut meal respectively, and noted that their value varied with the species of fish and the parts of the fish used in their preparation. Sardine meal has been found to give excellent results (Almquist *et al.* (8), Sherwood and Couch (219)), probably because it is manufactured largely from whole sardines. Although Almquist *et al.* (8) found that dogfish meal gave very inferior results in chick rations, later work by Rhian and co-workers (195) indicated that, although dry rendered dogfish meals had little value as

protein feeds for chicks, meals produced by a wet process were equal in quality with fish meals generally used. This is rather surprising in view of the fact that dry rendered meals were found equal to wet rendered meals in protein value by Record *et al.* (194) and even superior by Wilgus *et al.* (262).

(c) Milk Products

Although the present tendency seems to be to evaluate milk products chiefly on their riboflavin content, one should not overlook the importance of the milk proteins. Their high biological value has been discussed by McCollum *et al.* (156). These proteins (85% casein and 14% lactalbumin), while they appear to be somewhat low in arginine and glycine, are particuarly high in trytophane, methionine and lysine (Table 2). Lactalbumin, the chief protein in whey, would appear to be quite as valuable as the combined milk proteins. The value of milk products as animal protein supplements in both chick and laying rations is well attested by the results of many investigators. Roberts and Carrick (199) found that chicks grew equally as well to 10 weeks of age on these rations containing meat and bone scraps and dried skim milk in proportions of 3 : 1, 2 : 2, 1 : 3 respectively. Some workers have found dried milk to be somewhat superior to meat scrap for chick rations (Johnson and Brazie (123)), and for laying rations (Henderson (109)). Paci (183) noted that skim milk could entirely replace meat meal in the diet of chickens. Wiegner and Tscherniak (260), and Weinmuller and Mantel (258), noted that dried skim milk or liquid skim milk were equal or superior to fish meal for stimulating egg production and Bunger *et al.* (48) and Lang (140) reported that liquid skim milk could satisfactorily replace all other protein supplements in the diet of laying hens.

Ott *et al.* (182) added dry skim milk to an all mash ration, formulated to meet all known nutritive requirements, and observed an increase in the rate of growth during the first 2 weeks, total feed consumption and gain in weight during the growing period, feed efficiency during the early part of the growing period, body weight at sexual maturity, and percentage hatchability of the fertile eggs. On the other hand, investigations at the Ontario Agricultural College (85) have shown that, from the standpoint of egg production, powdered buttermilk was somewhat inferior to fish meal. The best results from the standpoint of hatching power of eggs, were obtained when powdered buttermilk was used in combination with beef scrap or fish meal in rations containing cod liver oil.

In general, all the milk products commonly used in chick rations appear to be highly satisfactory as sources of animal protein, and the choice will depend largely on the cost, availability and convenience. Card (61) found that when fed with an all mash basal ration, there was no significant difference in the average weights at 22 weeks of age of pullets which received sour skim milk or fresh butter milk ad libitum, condensed buttermilk fed at the rate of 0.6 pounds to one pound of mash and dried buttermilk fed at the rate of 20% of the mash. Mussehl and Ackerson (172) found that dried buttermilk and dried whey, when fed at the same protein level, were of equal value for chick growth, but that both were some-

what superior to dried skim milk. Roberts (198) found liquid skim milk and condensed buttermilk to be equal or superior to liquid buttermilk when fed with the same mash. Carstens and Prufer (59) observed that buttermilk curd was unsatisfactory for egg production unless supplemented with fish meal. Three types of curds were analyzed by Zimmermann and Malsch (267) and were found to contain substantial amounts of all the essential amino acids except cystine.

Although several workers (88, 75, 167), using rats as experimental animals, reported that exposure to relatively high temperatures reduced the biological value of the milk proteins, there is no evidence that modern methods of preparing milk products impair their protein value for practical poultry feeding. Furthermore, there is no evidence that there is any difference in feeding value between sour and sweet milk when the same protein or solids content of each is maintained. It is possible that high water content of the liquid form of milk products may limit the amount of protein consumed by the bird. If the drinking water supply is restricted, however, the birds should consume sufficient milk. Roberts (198) noted that it was practical to feed a mash containing 10% meal scraps when liquid milk was given as the only drink.

(d) Soybeans and Soybean Oil Meal

The chief protein of soybeans is glycinin which, according to Osborne and Campbell (180) comprises 80 to 90% of the total crude protein of soybeans. The amino acid composition of glycinin has been studied by Osborne and Clapp (181), Csonka and Jones (68), and Baernstein (29). Of more practical use, however, are analyses by Block and Bolling (28) of the mixed protein of the soybean. Their values are given in Table 3. Included for comparison are data for casein compiled by Calvery (57).

TABLE 3.—COMPARISON OF THE AMINO ACID COMPOSITION OF SOYBEAN PROTEIN AND CASEIN

Amino acids	Soybean protein[a]	Milk casein[b]
	%	%
Glycine	0.97[c]	0.5
Arginine	5.8	3.8
Histidine	2.3	2.5
Lysine	5.4	6.0
Tyrosine	4.3	6.6
Tryptophane	1.5	2.2
Phenylalanine	5.4	3.9
Cystine	1.0	0.3
Methionine	2.0	3.4
Threonine	4.0	—
Leucine	6 to 8	9.7 (Leucine and Isoleucine)
Isoleucine	0.4	
Valine	4 to 5	7.9
Sulphur	1.1	—

[a] Data of Block and Bolling.
[b] Data compiled by Calvery.
[c] Glycinin Osborne and Clapp.

Cooking the raw soybeans definitely improves the nutritive value of the soybean proteins. Hayward and coworkers (97, 99) and Wilgus *et al.* (264) showed that the application of heat during the preparation of soybean oil meal increased the nutritive value of the soybean and attributed this effect chiefly to an increase in the biological value of the protein. Later work (Hayward *et al.* (101), (98); Gericke and Van der Merwe (83)) suggested the heating process rendered available the sulphur-bearing amino acids, cystine and methionine. According to Almquist *et al.* (18), methionine was the principal limiting factor for the growth of chicks in raw soybeans. They reported that heated soybean protein was slightly deficient in methionine at a 20% protein level but was complete in all other amino acids required by the chick.

The lower nutritive value of the unheated protein may be partly responsible for the rather poor results from the feeding of raw soybeans to chicks and hens. Reports from the Delaware experiment station (Tomhave and Mumford (247, 249)) indicated that ground raw soybeans could not be substituted for any of the buttermilk or more than one-third of meat scraps of a ration without seriously affecting growth, mortality and utilization of feed. Raw soybeans in the diet of pullets tended to reduce egg yield especially when the level in the laying ration exceeded 6.8%. These results could not be attributed entirely to the fat content of the ground soybeans since the decrease in yield following the addition of the extracted oil was less than with the addition of the oil containing bean. Tomhave and Mumford (248) noted, however, that ground soybeans fed at levels up to 10.4% in an all mash laying ration had no detrimental effect on the keeping quality of eggs in storage 4, 6, or 9 months.

In general, more satisfactory results have been obtained with soybean oil meal, during the preparation of which the bean is exposed to a certain amount of heating. As early as 1920, Phillips *et al.* (190) obtained good growth on a ration of corn supplemented with 10% soybean oil meal and minerals. Carver *et al.* (63), however, obtained very poor growth when soybean oil meal was used as the sole protein supplement in poultry rations but showed that it should be used in connection with animal protein concentrates. Ackerson *et al.* (3) found growth was unaffected by replacing $\frac{1}{3}$ of the meat meal and fish meal of a control ration with soybean oil meal. For broiler rations, Roberts and Carrick (201) reported that rapid growth could be obtained and the risk of overfeeding minerals eliminated by replacing part of the meat and bone meal with soybean meal. They obtained excellent results with a ration containing 10% soybean meal, 10% meat and bone scraps and 5% dried skim milk and observed no detrimental effects when the percentage of soybean oil meal was raised to 21%. Irwin and Kempster (120) found an even greater substitution of meat meal and dried buttermilk to be satisfactory, noting that 25% soybean oil meal in combination with 2% animal protein supplements gave gains equal to control rations containing 5% dried buttermilk and 10% meat scrap. However, for most rapid and economical gains, they recommended rations containing somewhat greater proportions of meat scraps or meat scraps and dried buttermilk to soybean oil meal.

The effect of soybean oil meal in the diet of the hen was studied by Wilgus and Gassner (265) who observed that a ration containing 16% soybean oil meal gave poor reproduction. Reduction of the oil meal to 6% and the addition of meat scraps greatly improved the results. Apparently riboflavin and manganese were not responsible for the effects. These workers suggested that the goitrogenic action of soybean which had been observed by several workers might be related to its depressing effect on hatchability. Byerly *et al.* (52) found with pullets that a 20% drop in winter hatchability resulted when soybean oil meal was used as the sole protein concentrate and fed at a level of 20%. However, they obtained satisfactory results when part of the oil meal was replaced with beef scraps. It was later reported by Titus (246) that yearling hens on this same diet showed no drop in winter hatchability. Obviously the age of the birds may play a considerable part in determining the utilization of a particular diet.

For a literature review up to 1938 of the nutritive properties of soybeans the reader is referred to an article by Hayward *et al.* (100).

(e) Cottonseed Meal

Little is known of the amino acid composition of cottonseed meal, since figures are available only for the globulin fraction which comprises about one-third of the total protein (Fontaine *et al.* (79)). Marais and Smuts (149) showed that cottonseed meal was deficient in certain unidentified amino acids and minerals necessary for the growth of rats.

A notorious characteristic of cottonseed is its content of gossypol, an organic substance believed to be toxic. However, there is no evidence to show that cottonseed meal is seriously toxic to chickens, at least, when fed in moderate amounts. Commercial meals are much lower in gossypol than the raw seed. Thornton (243) reported that the cooking process prior to the pressing operation inactivated the gossypol, and Olcott and Fontaine (179) could find no evidence of free gossypol in samples of several commercial meals as measured by the growth of rats. A similar report was made by Hunt (117).

Apparently, however, cottonseed meal does contain certain substances, including small amounts of gossypol, detrimental to egg quality (Lorenz and Almquist (141); Swensen *et al.* (233)) and caution must be used when including the meal in laying rations. Many workers at southern stations (Thompson (242), Walker *et al.* (256), Kempster (132), Sipe (221)) reported that eggs from hens fed varying amounts of cottonseed meal while normal when fresh, developed dark yolks and pink whites on storage. Sherwood (217) noted that eggs laid by hens which received an "all mash" feed containing 9% cottonseed meal did not store well. In a later study, Sherwood (218), showed that only a small percentage of eggs laid by hens, receiving 2 gm. of cottonseed meal daily, deteriorated on 5 months' cold storage, but as the amount increased, the percentage of deterioration increased. He also produced evidence to show that the injurious substance was associated with the oil fraction. Smith (228) found that when cottonseed meal was fed at a level of 2.5%, the storage quality was normal.

However, considerable success has been obtained with cottonseed meal in rations for growing chicks. As early as 1914, Hartwell and Lichtenthaeler (96), found that when mineral supplements were supplied, and the chick limited to the same nitrogen intake, the gains were not very different whether cottonseed meal or beef scraps formed the chief sources of protein.

Mussehl (171) reported that cottonseed meal ranked second to soybean meal as a plant protein supplement for growing chicks, and that, when the protein supplement consisted of equal parts of cottonseed meal and meat and bone meal, growth was satisfactory and only slightly less than that obtained with meat and bone meal as the sole supplement. Reports from Texas (Sherwood and Couch (219, 220), indicated that cottonseed meal was about equal in value to soybean oil meal for growing chicks when fed in combination with animal protein supplements. They found that when vacuum dried fish meal was used to make up 6% of the chick ration, the remaining 12% could be made up of meat and bone scraps, soybean oil meal or cottonseed meal, using 6% of each.

Berry (35) found that a replacement of 10% meat and bone scraps with 10% cottonseed meal, in a ration containing 10% buttermilk, gave somewhat slower and less efficient growth up to 8 weeks and noted that, in the production of broilers, there was no saving by the inclusion of cottonseed meal in the ration. However, from 8 to 24 weeks, in a growing mash containing 10% dried buttermilk, cottonseed meal supplied the added protein just as efficiently as did meat and bone scraps. There was no detrimental effect on the first year's egg production of pullets fed the cottonseed growing ration. Experiments conducted at the South Carolina station (Ringrose and Morgan (197)) indicated that, in a ration with an adequate supply of riboflavin, cottonseed meal could replace up to at least three-quarters of the meat scraps. Growth on this ration did not differ significantly from that obtained on a control containing 19.7% meat scraps (50% protein), 7.5% dried whey and 5% dehydrated alfalfa meal. A small but significant improvement in growth was noted when cottonseed meal replaced about one-quarter of the meat scraps.

Bethke and co-workers (36) compared cottonseed meal and linseed meal and found the former definitely superior. Later work by Ackerson *et al.* (4) substantiated this finding. They replaced cottonseed meal with linseed oil meal as one-third (5% of the ration) of a concentrate in conjunction with meat scraps and fish meal and found that a slightly lower rate of gain (gain in weight divided by the weight of the dry matter fed) was obtained up to 6 weeks. They noted that neither linseed oil meal nor cottonseed meal were as efficient supplements to meat scraps and fish meal as were dried buttermilk or soybean meal. They pointed out that where rapid growth is desired there is some disadvantage in the use of cottonseed meal.

While it is difficult to generalize the above findings, it seems safe to conclude that, with an adequate supply of riboflavin and minerals, satisfactory growth can be maintained when cottonseed meal replaces approximately one-half of the animal protein concentrate or makes up about 10% of the ration.

Some disagreement among investigators as to the relative values of cottonseed meal and other protein supplements can be expected. Apparently, cottonseed meal from different sources and produced by different methods of manufacture may differ greatly in feeding value. Investigations by Olcott and Fontaine (178, 179) showed that the growth promoting value of the protein of cottonseed meal for rats was greatly reduced by autoclaving the meal. The heat treatment caused a marked reduction in the solubility of the nitrogenous constituents in water and in 3% NaCl. Undoubtedly, there is need for improvement in the methods of processing of the meal and for the development of a suitable process for removing the detrimental substances responsible for egg deterioration.

(f) Peanut Meal

Arachin and conarachin are the principal proteins of the peanut, the former making up about 60% of the total protein. Brown (44) gave the following percentage amino acid values for arachin and conarachin respectively: cystine, 1.51, 2.92; methionine, 0.67, 2.12. Early work by Johns and Jones (122) showed a very high arginine content for arachin. Studies by Smuts and coworkers (229, 230, 231), in which rats were the experimental animals, indicated that the proteins of peanut meal had a biological value of 12.5% lower than those of cottonseed meal and were probably deficient in methionine. Beach and White (34) concluded that methionine was the limiting nutritive factor of arachin. This was confirmed by Klose and Almquist (138) who showed that arachin was seriously deficient in methionine but well supplied with cystine. They found that chicks on a ration containing 20% arachin, 5% gelatin and 5% dried yeast required the addition of at least 1% dl-methionine to the ration for satisfactory growth.

In discussing the value of peanut meal in chick rations, Almquist (17) stated "arachin will not support satisfactory chick growth unless lysine, glycine, methionine and tryptophane are added in substantial amounts and it seems that peanut meal cannot be expected to yield good results in chick rations without heavy reinforcements by proteins of animal origin." This statement is substantiated by feeding trials with peanut meal. Bryant (46) found that, in ration containing 5% dried milk, peanut meal supplemented with minerals could be used to replace 50% of the meat meal but that 100% replacements gave much poorer growth. Sherwood and Couch (220) found that the protein of peanut meal was inferior to that of cottonseed meal or soybeam meal as a supplement to animal protein.

For laying rations, Dearstyne, *et al.* (72), found that a ration containing as protein supplements 20% peanut meal and 3% dried milk (scratch grain fed in addition) did not reduce egg production, hatchability or livability of the chicks. Earlier work by King and Cottier (135) also showed that peanut meal when combined with milk was highly satisfactory for laying rations.

(g) Linseed Oil Meal

There is little information available on the amino acid composition of the protein of linseed meal. Marais and Smuts (149, 150) found that the biological value of linseed meal, as measured by feeding experiments with

rats, was increased somewhat by the addition of cystine. Analysis by Hamilton and co-operators (92) also indicated that linseed oil meal was low in cystine and also rather low in lysine.

Rather unpromising results have been reported concerning the use of linseed oil meal in poultry rations. No advantage was found by Christiansen and coworkers (66) from the substitution of 5% of the soybean oil meal in chick rations with linseed oil meal. Bethke and coworkers (36) found that chicks fed on rations containing 10% of linseed oil meal grew slowly and exhibited a marked intestinal disorder and high mortality. Ackerson *et al.* (4) noted that neither linseed oil meal nor cottonseed meal were as efficient as dried buttermilk or soybean oil meal when fed to growing chicks as one-third of the protein concentrate in conjunction with meat scraps and fish meal; cottonseed meal when compared with linseed oil meal gave slightly better gains per unit of feed and nitrogen fed. Similar results were obtained by Sherwood and Couch (220) who found that, in rations containing fish meal, soybean oil meal and cottonseed meal, partial substitution of the soybean oil meal or cotton seed meal with linseed oil meal (2 and 4% of the ration) gave lower gains. Moreover, the grams of feed required to produce a gram of gain was higher.

Experiments conducted by Slinger *et al.* (225) showed that 4.5% of linseed oil meal could not satisfactorily replace its protein equivalent of meat meal in a growing ration. Moreover, the addition of larger amounts of linseed oil meal resulted in an impairment of health and growth so marked that it suggested the presence in linseed oil meal of a "toxic" factor or factors. Further work (226) indicated certain meals contain up to 412 mg. of HCN per kilogram of meal. This is interesting since several workers reported the presence of rather large amounts of cyanophoric compounds in flaxseed and flaxseed oil meal. Villaume and Gillet (253) obtained 240 to 600 mg. of HCN from 1 kilogram of fresh linseed cake. They found this figure to decrease with the age of the cake. Santoro (209) examined samples of flaxseed cakes from several factories and found that all showed strong cyanogenesis. Only one product, however, which yielded on hydrolysis 200-250 mg. HCN per kilogram produced digestive disturbances in cattle.

(h) Distillers' By-products

The residue which remains after the alcohol is distilled from the fermented mash constitutes an important by-product from the distilling industry. This residue consists of solid matter, which contains appreciable amounts of yeast, and a liquid portion which contains various substances in solution.

The feeding value of the by-product varies considerably, depending on the fractions which it includes and the grain from which the mash was prepared. The available literature relating to the value of distillers' by-products used as protein supplements in poultry rations is relatively small. However, it is sufficient to indicate that, while the protein of such products is relatively incomplete, which is not surprising in view of the known

deficiencies of the cereal proteins, it has value when used along with other supplements. D'Ercole *et al.* (73) obtained poor growth with chicks when dried distillers' grains (solid portion of the residue) supplied approximately one-third of the protein of a ration in which the sole animal protein source was 5% dried skim milk. Sloan (227) reported that special distillers' dried grains (residue, following extraction with hexane) when fed in combination with meat scraps, dried skim milk and soybean oil meal satisfactorily comprised 12 to 15% of the total crude protein of a growing ration, but that a 22 or 30% level of special distillers' dried grains fed as the sole protein supplement gave very poor growth.

Using corn distillers' dried grains with solubles (both the solid and liquid residue), Shea *et al* (216) found the protein to be of good supplementary quality for chick rations. When a control ration containing 5% soybean oil meal, 7.5% dried milk, 6% meat scrap and 2.5% fish meal was used and the protein level was kept constant, the dried grains successfully replaced 100% of the dried skim milk or 50% of the soybean oil meal. One-half the dried skim milk and all of the fish meal were also successfully replaced.

Using a similar product in laying ration, Dickens *et al.* (74) found that, provided the protein content was kept constant, all of the dried milk and fish meal or all of the fish meal and part of the meat scraps could be satisfactorily replaced, although hatchability was lessened somewhat.

(i) Hempseed Meal

Edestin is the principal protein of hempseed comprising about 50% of the total protein in the seed. Several workers, including Lugg (142, 143), Bailey (30), Kassel and Brand (130) and Kapeller-Adler (129) have investigated the amino acid composition of edestin. An examination of data compiled by Calvery (57) from the results of various workers reveals that edestin is low in methionine, tryptophane and lysine. Obviously, however, a knowledge of the amino acid composition of only 50% of the total protein does not permit a very useful evaluation of the amino acid composition of hempseed.

It should be mentioned that heat treatment may be detrimental to the nutritive value of edestin. Waisman and Elvehjem (255) found that edestin autoclaved 5 hours at 120° C. did not produce as good growth in rats as untreated edestin and that the addition of lysine to the autoclaved edestin gave a marked stimulation in growth. Keisel and Kusmin (134) noted that heat caused a decrease in the tyrosine, histidine, tryptophane and arginine content of edestin.

(j) Miscellaneous Vegetable Proteins-Sunflower Seed Oil Meal, Rapeseed Oil Meal, Corn Gluten Feed

Sunflower seed oil meal has long been used as a popular stock feed in Europe, especially for dairy cattle. As far as the author is aware it has not been used extensively as a poultry feed. A few reports, however, are available.

Tabokoff (235) from the results of feeding trials with pullets under Bulgarian conditions found that sunflower oil cake could be used to the extent of 25% of the daily feed with satisfactory results from the standpoint of financial returns from egg production. This conclusion, however, was greatly influenced by the high cost of animal protein concentrates in Bulgaria. Halnan (90) reported that sunflower seeds were a good source of protein and energy for poultry. Experiments, by Pettit *et al.* (189), indicated that satisfactory growth of chicks to 10 weeks could be obtained with a ration containing 10% buttermilk powder and 14% sunflower seed meal. Satisfactory egg production and hatchability were obtained when sunflower seed oil meal replaced all of the soybean oil meal and one-half of the meat meal in a laying mash. Complete data concerning the amino acid composition of the sunflower protein is lacking although Blazowistacheriski and Schubert (39) reported 9.10% arginine, 14.3% histidine, and 1.80% lysine in the globulin fraction of sunflower seed protein.

Rapeseed meal was fed to pullets at a level of 10% of the mash with satisfactory results (78). Pettit *et al.* (189) found that rapeseed oil meal was a satisfactory substitute for meat meal in amounts up to 14% of a chick starter ration but that a 20% level replacing all the meat meal resulted in considerable mortality and a reduction in rate of growth. It has been observed that high levels of rapeseed oil meal fed to cattle have produced serious digestive disturbances, these effects being attributed to the presence of certain glucosides in the rapeseed. Moreover, the meal is somewhat unpalatable and is not liked by the animals. These may be important factors to consider when incorporating rapeseed oil meal into poultry rations.

Some work in the author's laboratory (223) with corn gluten feed (a by-product of the starch industry containing 23 to 25% protein) has shown that, while it is inferior to soybean oil meal as a protein feed, it can satisfactorily replace two-thirds of the meat meal in a chick growing ration and can be fed to layers and breeders.

(k) Methods for Evaluating Protein Supplements on a Numerical Basis

Attempts have been made to supply the poultry industry with information on the relative supplementary value of various protein concentrates when added to the cereal basal diets commonly used in practical poultry rations. In view of the fact that the remarks in section 5 are applicable to most of these studies, it is obvious that the numerical values obtained can provide only rough guides to the relative feeding value of the various protein supplements. Moreover, when ad libitum feeding is practised, relating gain in weight to protein consumed does not give a true measure of protein efficiency. Values so obtained cannot accurately represent biological values of a series of protein feeds since the ratio of gain in weight to protein consumed is positively correlated to the rate of gain itself. Palatability and feed consumption are also complicating factors in ad libitum feeding. It should be stated that the investigators whose work is cited below have for the most part recognized the limitations of the methods which they have proposed.

Two of these methods have been an evaluation of the efficiency of the protein supplements relative to casein. Wilgus, Norris and Heuser (263) determined the percentage N stored by the normal chick during the 7th week of age when fed on a diet containing the supplement under study, divided this by a similar value obtained with a standard casein diet and multiplied by 100. A simple N balance method was employed in which only the total N consumed and the total N excreted were considered. Heiman *et al.* (107) assigned to the various supplements a "gross protein value." This was described as a relative numerical expression of the growth response (gain over control per gm. of supplementary protein consumed) obtained with protein supplements when added to a diet believed complete in all respects except quality and quantity of protein. The test was preceded by a 2-weeks protein depletion period during which a diet containing 8% plant protein was fed. Sufficient of the supplement under test was then added to bring the protein level of the ration up to 11%. All values were reported as relative to casein which was assigned the arbitrary value of 100.

Almquist *et al.* (8, 13) described a chemical method for the estimation of protein quality, i.e., an estimation of the feeding value was arrived at by chemically-differentiated forms of N considered to be of greatest influence on the nutritive value. The protein quality index was calculated from the following formula, the numerical values of which are empirical.

$$\text{P.Q.I.} = A - (B + 0.6C) + 0.4D.$$

where A = % total N precipitated by a copper reagent.

B = % total N not digested by pepsin—HCl.

C = % total N soluble in hot water.

D = % total N precipitated by phosphotungstic acid.

The values as found using this formula correlated well with the nutritive values measured by the growth response of chicks.

One other method may be mentioned here. St. John *et al.* (211) used a modification of Mitchell's formula (162) for the determination of biological value. Their low nitrogen diet analysed 0.042% nitrogen and consisted of starch 63%, sugar 15%, salt mixture 5%, C. L. O. 7%, charcoal 5% and grit 5%. The application of Mitchell's method to poultry involved some difficulty since in birds the urine and feces are not voided separated. Instead of attempting a separation, St. John *et al.* considered that the uric acid and ammonia N represented the urinary N.

6. PROTEIN REQUIREMENT OF TURKEYS

Poults during early growth require a somewhat higher level of protein in their diet than do chicks. Like chicks, however, this requirement is considerably reduced in the later growing periods. Asmundson and Jukes (25) reported results which indicated that the most satisfactory protein levels in the entire ration, from the standpoint of the most rapid and efficient gains, were, 1 to 6 weeks, 24% protein; 7 to 12 weeks, 20% protein;

13 weeks to maturity, a decrease in the protein to about 15%. The experimental findings of other workers (Roberts (202), Hammond and Marsden (95), Headley and Knight (102), Mussehl and Ackerson (269)) are essentially in agreement with these conclusions. There is also evidence (95) that, although live weight gains from about 12 weeks on are not proportional to the protein content of the ration, birds which are heaviest at 12 weeks maintain this advantage to maturity.

There is a suggestion that climatic differences from one locality to another may have quite a marked influence on the nutritive requirements. Robertson and Carver (205) reported from the Washington Experiment Station that increasing the protein level of the concentrate (grain fed in addition) to 39% gave more rapid growth and more efficient utilization of feed. Funk (81), on the other hand, on the basis of a trial in Missouri, claimed that there was no advantage in the use of mashes analyzing higher than 30% protein. It is interesting, in this connection, that Barrett *et al.* (31, 32) and Hammond and Marsden (95), observed that following the first period of most rapid growth, birds fed mashes differing in protein content have a tendency to adjust their protein intake to a common level by varying the ratio of the mash and protein consumption.

While some animal protein in the ration is essential for best results, it appears that a considerable portion of this can be replaced by vegetable protein with no harmful effects. Hunter *et al.* (119) showed that from the standpoint of growth, mortality and food consumption during the first 12 weeks, soybean oil meal or corn gluten meal could satisfactorily replace 50% of any two of dried milk meat scraps or fish meal when these three animal proteins were included in the ration (24% protein) in equal parts. In the subsequent period of 13 to 25 weeks, dried milk and meat scraps were used in the diet in the proportions of 1 to 2 to give a protein level of 16%. It was found that as much as two-thirds of both constituents could be satisfactorily replaced by soya or gluten meal. Funk and Kempster (80) found soybean oil meal superior to either cottonseed meal or corn gluten meal for starting and growing turkeys. All three supplements comprised 10% of the ration. Milby *et al.* (192) reported that linseed meal was not suitable for turkey rations; 10% or more of linseed meal in the ration caused 100% mortality. It has been already noted that similar results have been found with chickens.

It should be mentioned that the inclusion of a large proportion of fish meal in turkey rations may cause objectionable fish flavours and odours in the turkey meat. For this reason it was recommended by Asmundson *et al.* (24), Marble *et al.* (151), Bryant and Stevenson (47) and others that fish oils or fish meal should be omitted from the diet during the few weeks previous to killing. This fishy flavour apparently does not come from the intestines after killing, since removal of the viscera immediately following slaughter did not prevent the taint (Schaible *et al.* (212)).

The practical feeding and management of turkeys have been discussed by Marsden and Lee (153); Traves (252), Taylor (236), Noland (174), Scott (215) and many others.

7. PROTEIN REQUIREMENT OF DUCKS

Only a few reports are available on this subject but it seems evident that ducks grow satisfactorily during the early growth period on a somewhat lower level of protein than do chicks. Horton (27) found that White Pekin ducklings grew more rapidly and ate less food on a ration containing 19% protein than on a ration containing 12%. At 5 weeks of age the birds on the higher protein ration were twice the weight of those on the lower. However, at 15 weeks the weights of the two groups were approximately equal. An examination of the composition of the two rations used by Horton reveals that the protein level was raised by the addition of 5% milk and other ingredients entirely absent from the low protein ration. Thus, other factors in addition to protein level may have influenced his results. Hamyln *et al.* (93), from more extensive experiments, concluded that ducklings make more efficient utilization of protein than do chicks and that the optimum level for growing ducks to 10 weeks is somewhat less than 18%. Their results indicated that a protein level of 25% was approaching an excess and was detrimental to growth. These conclusions were largely confirmed by Roberts (200) who found that a protein level of 17% was as satisfactory as levels of 18 and 20%, the adjustment in protein content being made by varying the amount of meat meal in the ration. The relative value of various protein supplements in duck feeding has not received much attention. There is a suggestion, however, that the duck may not be as critical in its requirements as the chicken. The experiments of Hamyln *et al.* (93) indicated that meat meal was as satisfactory as a mixture of skim milk powder, fish meal and meat meal, when the rations were fed at the same protein level. Roberts (200) observed that a combination of 10% meat scraps and 5% dried milk was superior to 10% meat scrap alone. The percentage of protein, however, was somewhat lower in the latter ration. Investigations in England (MacDonald and Kay (144)) have shown that ducks on grass runs make as satisfactory gains with 10% meat meal as the sole protein supplement as with a combination of meat meal, dried milk and soyabean meal fed at the same protein level. Also from England is a report (Tallent (240)) that fish meal and meat and bone meal gave equal egg production but that the former produced a higher percentage of first grade eggs.

Since nutritive requirements are so closely related to rate of growth it is interesting that Milby *et al.* (159) observed the growth rate of ducks and geese to be almost double that of chickens, turkeys or pheasants during the first few weeks following hatching. However, they also observed that ducks and geese declined in growth rate much more rapidly and at an earlier age (4 to 5 weeks) than the other three species. In view of this, a reduction of the protein level of the duck ration at about 4 weeks might prove more economical than maintaining one level up to 12 weeks or more.

8. PROTEIN REQUIREMENT OF PIGEONS, PHEASANTS, QUAIL

The rearing and feeding of pigeons from a practical standpoint has been discussed by Platt and Dare (191) Mangold and Damkohler (147, 148) and Lee (140a).

As far as is known the pigeon grows more rapidly than any other bird during the first 20 days after hatching. During this period the young squab is nourished on "pigeon milk," a white liquid very high in protein, secreted in the crop of the parent pigeon. Apparently, the pigeon is quite sensitive to the quality of its protein intake. Carr and James (58) on the basis of experiments in which they supplemented a corn and mineral ration with "pigeon milk" suggested that the crop glands may synthesize certain amino acids which are necessary for maintenance and growth. Carter and O'Brien (60) showed that the loss of weight exhibited by pigeons fed solely on polished rice was partly due to inadequate protein intake since supplementing this diet with caseinogen or gluten gave a partial weight recovery.

The young pheasant seems to grow most satisfactorily on a somewhat higher protein level than is suitable for the domestic chicks. Callenbach *et al.* (53) observed that pheasants made the best growth on a diet containing approximately 28% protein. Similar results were obtained by Norris *et al.* (177) who concluded that for early rapid growth pheasants should be given a diet containing 24% protein. Birds on rations containing 15 and 18% protein were markedly retarded in growth and were given to feather pulling and canibalism. Skoglund (222) found that soybean meal supplemented with some low grade meat meal and fish meal formed an ideal substitute for expensive high grade meat meal. He also recommended 65% meat meal as a desirable protein concentrate, observing that because of the high protein requirement of young pheasants the feeding of low protein meat meals gave an excess of minerals and favoured the development of perosis. A similar conclusion in regard to the danger of perosis on certain diets had been drawn earlier by Callenbach and Hiller (54) who recommended the use of meal meat containing 75% protein.

There seems to be very little information recorded in the literature regarding the protein requirements of bobwhite quail. Norris (176) fed protein levels of 21, 24, 27, 30, 33, and 36% to battery reared chicks and showed by these experiments that the bobwhite requires 24 to 27% of protein in its diet for rapid growth.

For a detailed account of the feeding requirements of upland game birds (grouse, quail, pheasants, and wild turkeys) the reader is referred to a discussion by Nestler (128).

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RELATIVE BODY DEPTH AN EXCITING CAUSE FOR DEVELOPMENT OF KEEL BURSAE IN CHICKENS

S. Bird[3]

with

A NOTE ON MEASURING EQUIPMENT[2]

V. E. Hollinsworth[4]

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INTRODUCTION

Investigation of possible causes for the occurrence of disfiguring bursae formations over the ridge of the keel of poultry has been in progress at this laboratory since 1936. Until then solution of this problem had not been attempted and progress was therefore slow during the first five years, after which Hodgson and Gutteridge (4) published the initial report in this field on the principal leads followed to that date. These authors showed that in the main only males of breeds other than Leghorns were susceptible. They found the bursa fluid completely sterile but frequently containing erythrocytes, leucocytes and fibrin, and its protein level varying within the limits characteristic of normal plasma. It was further shown that bursae appear at the earliest about the age of 12 weeks and a little later in late hatched and in slow growing birds. They also found that poorly fleshed specimens were more susceptible than those of better type but did not pursue this lead further. Several physical body measurements were found to be not at all or poorly correlated to bursae incidence, the more important being body weight, circumference of tibia and keel depth as well as roundness of breast. The last mentioned was determined by the angle between the contours of the right and left pectoralis major muscles as measured by an instrument conceived by the present author and described by Gutteridge and O'Neil (3). Various forms of roosts and roosting conditions were found to be without influence on the incidence of bursae with the one exception of continuous roosting on wire netting. One family of Barred Rocks was discovered in which the males seemed to inherit resistance to formation of bursae. O'Neil (5) published a histological description showing these growths to be bursae under the skin and not blisters of the skin, wherefore he rightly proposed the abolition of the term breast blister. The outer area of the bursae walls was found to consist of highly vascular, loose, connective tissue whereas the inner zone largely consists of white fibrous connective tissue which is poorly supplied with blood vessels and therefore undergoes degenerative changes. Later, O'Neil (6) studied the influence of growth on development of bursae. Statements regarding variability as well as final numbers of birds were unfortunately not included in this report and the unavoidably large mechanical errors in the breast angle determinations with our instrument were not taken into account. This author confirmed the statement by

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Hodgson and Gutteridge (vide supra) that late hatched birds generally had a smaller tendency to develop bursae than those of earlier hatches. He also touched upon an important phase of the problem when he stated that "—those birds which grew at a more rapid rate . . . . . had a greater tendency to develop cysts" and "—at the same time . . . . . had sharper breast angles." He did not attempt to draw the basic conclusions as to why the slower rate of growth produces rounder breasts and why, therefore, such birds have less tendency to develop bursae.

Theoretical Considerations

Considering the nature of bursae, as described by the above mentioned authors, the hypothesis seems warranted that their immediate cause is friction or pressure exerted against the keel when a bird is resting in a sitting position. Such aggravating causes presumably would lead to pathologic development of the connective tissue covering the crest of the keel thus protecting the keel from more serious complications involving the periosteum. The picture is in fact somewhat similar to that which in human pathology is popularly known as a case of "housemaid's knee." If this be so, the question arises, why are some birds subject to the degree of aggravation which requires a bursa while others are not. It has been show by Bird (2) that individuals possessing great depth through the pectoral girdle relative to body weight must in fact be sharp breasted, since change in body weight is mainly determined by muscular volume. Inversely even birds which carry a very large volume of flesh but have a characteristically wedge shaped body conformation may be relied upon to show exaggerated depth through the pectoral region, Bird (1). Such birds may in consequence be expected to exert greater pressure on the roost than those of more shallow conformation and thus possess greater need for a protective bursa.

EXPERIMENTAL

The present phase of these investigations has been carried on through the years 1942 and 1943 in which the effects of relative depth and pressure on roost and the influence of these on inherited resistance were studied.

Relative Depth

Deviations from the simple regression curve of depth on body weight adequately describe the relative depth of birds since it was found that all determinations fall on the practically linear segment of the logarithmic curve. Various negative deviations of observed from expected depth will thus denote progressive shallowness while positive deviations will signify greater than expected depth. Depth, from the neural spine of the last cervical vertebra to the anterior point of the sternal crest, was therefore secured by callipers and measured from a millimeter scale. Body weight was measured in grams. Bursa condition of breast was designated as "N" for normal, as "−1" for very slight accumulation of tissue as recognized when lightly manipulated, and definitive bursae as "1", "2", "3", and "4" according to visible size. Barred Rock cockerels numbering 120

were measured at 26 weeks of age in the fall of 1942 and 99 males of the same breed in 1943. The analysis of these measurements is presented in Table 1.

TABLE 1.—SIZE OF BURSAE RELATIVE TO DEPTH OF BIRDS

Type of Bursae*	N	−1	1	2	3	4
1942						
No. birds	80	28	7	2	3	
Mean of observed minus expected depth m.m	− .50	− .75	+1.14	+9.5	+5.67	
1943						
No. birds	51	23	14	7	3	1
Mean of observed minus expected depth m.m	−1.22	− .96	+1.79	+5.71	+2.33	+11.0

* Only bursae above type "1" or 4.2% of all birds handled in 1942 and 11.1% in 1943 were large enough to cause degrading on the market.

In the 1942 analysis the mean square between bursae classes exceeded the error by 2.64 times. In 1943 this value was 2.23. In both years therefore the difference in mean relative depth of the birds in the different classes of bursa size would not occur by chance alone more than once in about 20 trials. However, considerable overlapping did occur between classes from which it is clear that other factors were involved.

Pressure on Roost

Some of these factors were revealed during a test in which it was attempted to measure directly the pressure exerted on the roost by the birds. An electrical pressure gauge was set up by Mr. V. E. Hollinsworth of the Dominion Observatory as shown in Figure 2. On this the birds were made to roost in the dark in positions which assured that only their keels rested on the movable section of the perch. When a bird was made to squat on the roost the indicator of the attached meter would at first record slight pressure with violent oscillations but gradually build up to the characteristic pressure of normal rest. At the same time the oscillations would become the record of the bird's respiration which raises and lowers the pectoral skeleton and thus rhythmically decreases and increases the pressure against the perch. The respiratory rhythm was in most cases between 18 and 30 beats per minute with an occasional bird showing sometimes extremely rapid but still constant rhythmic tempo. Birds with such increase in respiratory rate were nervous and excitable and these would in this manner throughout a night's roosting produce increased friction against the perch and thus presumably more readily acquire a bursa than a more placid bird of like body conformation. There would seem to be small room for doubt that a part of the variability attached to the mean observed minus expected depths of Table 1 was in fact caused by temperamentally induced variation in bursa acquisition.

When the ammeter recorded normal respiration and therefore establishment of normal roosting condition the mean value of repeated oscil-

lations was in each case determined as the characteristic pressure for a bird. The plot of pressure in grams on roost against deviations of observed from expected depth through pectoral girdle is shown in Figure 1.

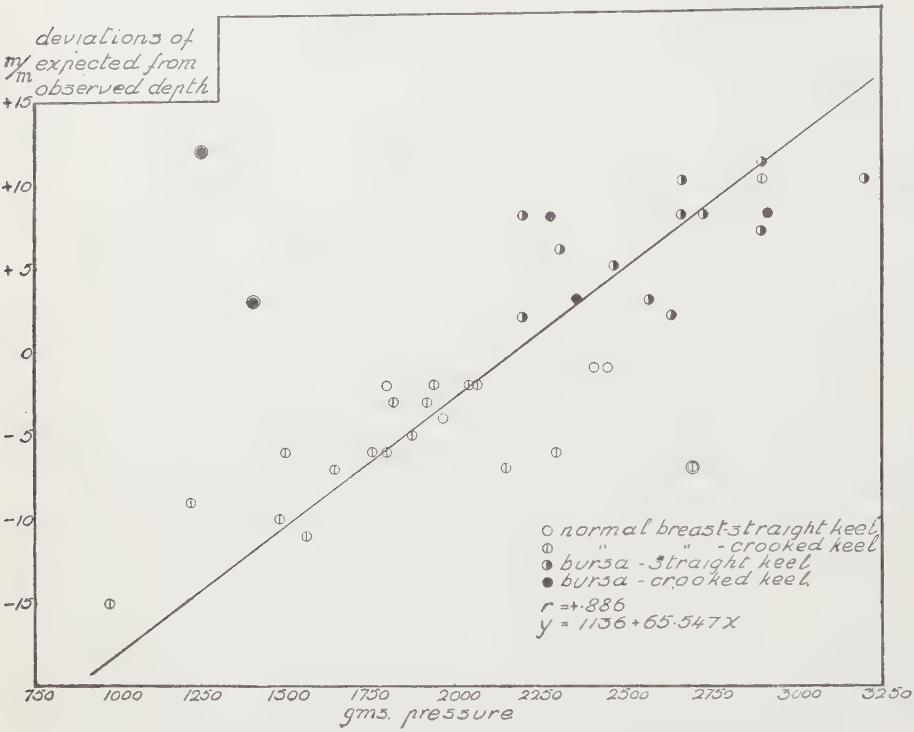

FIGURE 1. Pressure in grams (y) exerted on roost by 39 Barred Plymouth Rock males plotted against the deviations of their observed from expected body depth (χ).

The coefficient of correlation for 36 of the 39 birds tested was $r = + .886$ and the regression of pressure on relative body depth was $y = 1136 + 65.547\,\chi$. It will be noted that 3 values were outside the normal range of variation. These 3 birds were under such nervous tension that nothing could induce them to roost quietly. Two of these seemed always ready for flight thus pressing but lightly on the roost and the third cowered in fear and so produced abnormally heavy pressure. It is also noteworthy that of 18 relatively deep birds 17 had bursae and of the 22 birds with normal breasts 21 were relatively shallow. Altogether the evidence seems conclusive for the statement that keel bursae are the normal response to pressure, in this case depence against more serious effects from the pressure exerted against the roost by the keel of relatively deep birds.

It should be mentioned in this connection that 67% of the relatively deep birds which formed bursae had straight keels while 81% of the birds which were measured as shallow and were without bursae had crooked keels. It seems probable that misshaping of the cartilaginous keel blade of early life could take place without serious ill effects and so reduce the relative depth of the birds that bursae were not required.

During the last five years the overall incidence of bursae in this flock of Barred Rocks has been recorded each fall when the males were about 24 weeks old. These data are presented in Table 2.

TABLE 2.—INCIDENCE OF BURSAE THROUGH FIVE YEARS

Year	Sires with male progeny	Birds with bursae	From May to September	
			Rain	Sunshine
	no.	%	in.	hr.
1939	12	48.1	18.34	1230
1940	15	40.0	12.13	1127
1941	12	12.9	10.42	1279
1942	18	28.6	16.54	1099
1943	13	41.1	23.25	1132

It will be seen that a formidable variation in bursa incidence has occurred over these years. The impression might therefore easily be gained that this table effectively vitiated the above conclusions with regard to the importance of relative depth of body, since it cannot reasonably be argued that a flock in which several hundred birds are raised each year could change materially in mean depth from one year to another. It should, however, be remembered that the question is not one of absolute depth but of depth relative to body weight and that the latter may very well change abruptly between years depending on the prevailing better or poorer rearing environment. Meteorological phenomena would seem to be important to formation of bursae only to the extent to which they affect rearing conditions. The summary data included in Table 2 might possibly suggest that high rate of precipitation is of detrimental effect. Determination of body depth has not been a routine procedure in our flock and mean relative depth can therefore not be shown for the five years. However, two brothers of the family which has been regarded as genetically resistant to keel bursae were used as sires in the year 1942 and again in 1943. During the first year these males sired a total of 32 sons. In the progeny of each was found one −1 grade bursa or altogether 6.2%. In the second year 34 sons were sired with 9 showing bursae or 26.5%. During the latter year feather condition was excellent but crooked keels were numerous and body weight very inferior. These birds were therefore relatively deep in body with resulting high incidence of bursae. Even birds which generally are non-susceptible may thus develop a need to form bursae if their body conformation is such that this protection is desirable.

Genetic Resistance

Hodgson and Gutteridge (loc cit) showed that bursae appear at the earliest about the age of 12 weeks and that formation of new bursae increases numerically till the age of 18 to 19 weeks in birds growing at average rate. However, under conditions of induced slow rate of growth the appearance of bursae was delayed about two weeks with a lower incidence

than observed under normal conditions. When their Table 4 is recalculated to show the difference between normal and delayed rate of growth Table 3 is evolved.

Table 3.—Rate of new bursae development through rearing period

Age in weeks	9-11	12-13	14-15	16-17	18-19	20-21	22	Total %
% Bursae in								
Normal growth 159 birds	.63	4.40	5.03	8.81	12.58	7.55	1.25	40.25
Delayed growth 51 birds	—	1.96	0	3.92	0	11.76	1.96	19.60

Table 3 shows that slow rate of growth to some extent obviates the need for bursae and also causes a delay in their appearance till a later age. This table therefore fully bears out our recorded observations, namely, that a bird must weight at least 1200 gm. before it is capable of exerting the necessary critical pressure against the roost which incites the tissues to develop a protective bursa. It is a well known fact that the skeleton of poultry has a considerably higher growth rate than that which is characteristic of muscular development. Growing birds are therefore relatively thin and sharp breasted till the age of 18 or 19 weeks when the skeleton has virtually completed its growth, whereas muscular development continues till past the age of 40 weeks. Hence the peak in appearance of new bursae at this age when thinness of breast and massive weight combine to create the most aggravating pressure conditions. In slow growing birds the differential growth rates of skeleton and muscle are more nearly similar than in fast growing individuals. Slowly developing birds are therefore relatively plump and therefore relatively shallow with the consequence that in such birds the incidence of bursae is low. Since early in these investigations, it has been appreciated that somewhat slower rate of somatic as well as sexual development is characteristic of the family which until recently has been regarded as having inherited a certain resistance to formation of bursae. However, on the basis of the above mentioned facts the conclusion becomes inevitable that the males of this family are not relatively free from bursae because their connective tissue has developed a specific insensitivity towards this type of development but because their body conformation is of the type that does not need bursae. The character which is genetically controlled in this family therefore may be but low rate of development. This conception would give a logical explanation of the reason why keel bursae are rather recent phenomena and also why they have appeared later under prairie rearing conditions than in the East. Hence, "genetic" resistance should probably be based upon inherited relative shallowness of body since to select for slow rate of growth would be a retrograde step.

Hodgson and Gutteridge and also O'Neil have reported non-susceptibility to bursae formations in Leghorn males as well as in females of all breeds considered. Although the present phase of these investigations was confined to Barred Rock males, a tentative explanation why Leghorn males do not need the formation of protective bursae may nevertheless be

deduced from other data in our files. In the spring of 1939, 50 Rock and 65 Leghorn males were weighed and measured every third week from the age of 8 weeks. The mean weight and depth of body for these populations are presented in Table 4.

TABLE 4.—MEAN WEIGHT AND DEPTH OF BODY

Age in weeks	50 Barred Rock males		65 White Leghorn males	
	χ weight	y depth	χ weight	y depth
	gm.	m.m.	gm.	m.m.
8	653.3	84.7	609.3	79.2
11	990.4	103.9	869.7	97.4
14	1401.9	114.9	1139.0	103.1
17	1843.8	123.8	1431.5	110.3
20	2259.0	133.0	1617.3	115.5

It will be seen that at 14 weeks of age the Rocks had acquired sufficient weight, which, given a suitable body conformation, might produce the pressure that requires a bursa whereas the Leghorns attained this weight three weeks later. The regression of depth on weight of the Rocks was $y = 86.32 + 0.020444\chi$. When in this equation the mean weight of the Leghorns at 17 weeks is substituted for χ the value of y becomes 115.6 m.m. expected relative depth. The observed mean depth for Leghorns at this age was 110.3 and these birds therefore are 5.3 m.m. shallower relative to body weight than comparable Rock males. From Table 1 it may be seen that birds which do not require bursae are on the average 1.22 m.m. shallower than expected and it can therefore probably be assumed that due to their much greater relative shallowness Leghorn males do not develop the pressure against the roosts which requires a protective bursa. Thus the body conformation which is desirable in Barred Plymouth Rocks already exists in Leghorns. Although data on females have not been obtained at any time during our work it is but a matter of common observation that females at all times are rounder in the breast than males. As roundness of breast in most cases is dependent on relative shallowness it is presumably safe to say that females are at least as shallow relative to their body weight as are Leghorn males and females in general will presumably therefore not be in need of bursae formations.

SUMMARY AND CONCLUSIONS

It has been found that the incidence and severity of keel bursae in fowl is largely dependent on the magnitude of their depth through the pectoral region relative to body weight and that the weight of pressure which the keel of a bird exerts against the perch during roosting is highly correlated to its relative body depth.

Crooked keels presumably decrease the incidence and severity of keel bursae by reducing the relative depth of the bird.

Variations in bursae incidence from year to year, which cannot be due to changes in mean body depth in a flock, may be due to the other component of relative depth, namely, body weight, as this can easily change materially between years depending on rearing conditions.

Supporting data have been presented which indicate that the non-occurrence of bursae in White Leghorn males and in females is consistent with the thesis for bursae formation as developed herein.

From these data it is therefore concluded that keel bursae afford a beneficient protection against more serious injury which otherwise might result from the pressure exerted by the keel of relatively deep birds against the perch during roosting, and that freedom from bursae in rapidly growing birds can only be expected in families of inherited relative shallowness of body.

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NOTE ON MEASURING EQUIPMENT

In order to determine the total pressure that a bird exerts through the keel of its breast bone when roosting, special measuring equipment was required. This is illustrated in the accompanying photograph Figure 2 and is described briefly as follows:—

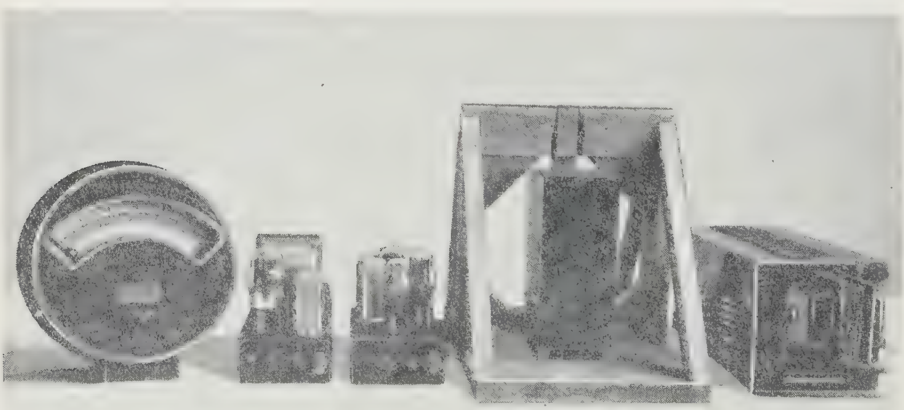

FIGURE 2. Measuring equipment.

A perch was constructed having a cut out mid section, 1 inch in width, which was fixed to a sensitive gauging head and adjusted to float in the gap from which it was cut. By means of a vacuum tube amplifier and associated voltage stabilizers, accurate readings of displacement, due to pressure on the gauging member, were obtained on the attached ammeter.

A calibration curve for the meter was made by balancing standard gram weights in increasing values on the floating member. By adjusting the magnetic poles in the gauge head an expanded scale was obtained, the range being from a minimum of 900 gm. to a maximum of 3500 gm. which proved sufficient to accommodate all birds tested.

While the measuring apparatus appears to be somewhat elaborate, it nevertheless proved ideal for the purpose. Other devices considered required considerable motion of the floating block to give an indication. This was not permissible since displacement of the block relative to the perch would cause relief of the pressure which it was desired to measure. In the gauging head shown the motion necessary for full scale reading was only a few hundredths of an inch.

Other attributes desired in the measuring device were ability to withstand suddenly applied loads, freedom from noise, restriction of lateral motion to avoid friction between block and perch, a remote indicator which could be located where light was available, and a minimum of operating adjustment, since both hands would be required for accurately placing the birds on the perch in such positions that their keels rested on the floating block only avoiding contact with the fixed perch.

The equipment used met all the above conditions. Although it was originally constructed for another purpose it was readily adapted to this project.

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Pasture is the natural food of cattle, sheep and horses. It is the sole food of the majority of cattle and sheep in the world. Even under intensive methods of production where fodder crops and concentrates are fed, these are, on the whole, merely supplementary to pasture either grazed or in the form of hay, grass silage or dried grass. Pasture is thus the main raw material of milk, meat, mutton, wool, hides and other products of the herbivora. With the possible exception of cereals, it is the most important world crop, and, indeed, the misguided exploitation of large

areas of land by cropping continuously with cereals has resulted in the major problem of soil erosion, the formation of wasting sores on the land surface that can best be healed by re-establishing pasture. Pasture is, therefore, of great economic importance, and undoubtedly this importance will tend to increase in the future.

A large amount of work has been done on "deficiency diseases." It has been found that mineral deficiencies in pasture are more important than vitamin deficiencies. If the pasture contains all the inorganic nutrients needed for health and is sufficient in quantity, there is unlikely to be a deficiency of either vitamins or protein.

It became obvious some years ago, that the great volume of literature which has appeared in recent years called for a new review of the literature on minerals in pastures. Miss Russell of the Imperial Bureau of Animal Nutrition was given the task and this publication is the result. Only those who have compiled and written such reviews appreciate the amount of laborious work needed to bring together all the available information from the many hundreds of papers published and arrange it in a logical and lucid form. Miss Russell has performed a service for which research workers in this field will be grateful. (From a foreword by Dr. J. B. Orr).

ALTERNATE HUSBANDRY. Imperial Agricultural Bureaux Joint Publication No. 6. Price 5 shillings.

In view of the fact that the term "alternate husbandry" has been widely used in agricultural literature for many years, it is first necessary to define the practice with reference to modern agricultural thought and to the discussion that follows in this publication. In this more restricted sense, alternate husbandry means a planned and regular (and yet at the same time flexible) alternation on every field of a farm or other agricultural unit of a period of arable husbandry (for the production of crops for human consumption, industry, or animal fodder) with a period of direct animal use, in which the composition of the herbage or forage mixture is so adjusted as to provide a maximum amount of fodder of the proper type and at the proper time for the animal crop that is to be produced, and at the same time so as to provide for the maintenance of an optimal state of fertility or productivity in the soil throughout the whole course of the rotation.

This publication of 156 pages has the following chapters:—

1. *Trends in Different Countries and Regions* by *R. O. Whyte.*
2. *The Influence of Herbage Rotations on the Soil* by *G. V. Jacks.*
3. *The Roots of Herbage Plants* by *R. O. Whyte.*
4. *Types of Leys and Their Component Species* by *R. O. Whyte.*
5. *The Animal Crop in Relation to Alternate Husbandry* by *J. E. Nichols.*
6. *Fertility Types, Production and Requirements* by *R. O. Whyte.*
7. *Alternate Husbandry and Current Agricultural Problems* by *R. O. Whyte.*
8. *Alternate Husbandry and Animal Diseases* by *E. L. Taylor.*
9. *Economic Factors in Changes from Other Agricultural and Pastoral Systems to Alternate Husbandry* by *A. W. Ashby and W. J. Thomas.*
10. *Bibliography.*

IMPERATE CYLINDRICA: Taxonomy, Distribution, Economic Significance and Control. Imperial Agricultural Bureaux. Joint Publication No. 7. Price 2s. 6d.

Imperata cylindrica is a grass species that is widely distributed in tropical and subtropical lands, especially in open country, on abandoned cultivated land and in deforested areas, where it may be the chief ground cover for many miles. It is one of the most common grasses in Africa, stretching from the tropics southwards to the Union of South Africa and northwards to the shores of the Mediterranean. It is also found in southern Europe and eastwards to Turkestan and Afghanistan, and is well known in India, Malaya, China, Japan and Australia.

This publication gives full taxonomic descriptions of the five varieties that are recognized within the species, *Imperata cylindrica*, and outlines the geographical distribution of each.

The effects of *I. cylindrica* on economic crops are generally adverse, and only in a few cases favourable; crops affected include quinine, tea, rubber, teak, fig, coconut, oil palms, sal, and abaca. The grazing and fodder value of *I. cylindrica* has been tested in a number of tropical and subtropical countries; the general conclusion seems to be that, although the grass does provide animal fodder in certain types of less advanced agriculture, it will ultimately be replaced by superior species managed according to modern methods. Other ways in which *I. cylindrica* can be used with varying success include thatching, paper-making, and soil conservation.

POTATO COLLECTING EXPEDITIONS IN MEXICO AND SOUTH AMERICA. II.—Systematic Classification of the Collections. By J. G. Hawkes. Imperial Bureau of Plant Breeding and Genetics. Price 7s. 6d.

The potato collecting expeditions in Mexico and South America, sent out by the Imperial Agricultural Bureaux, represent perhaps the first attempt within the British Empire to make a thoroughly scientific and exhaustive collection of indigenous plant material for the initiation of a large-scale breeding program. Unlike expeditions sent out by other countries in the past, the energies of the collectors were directed wholly towards the problem of potatoes, since no attempt was made to collect samples of food plants in general. This concentration of efforts enabled a very large and detailed collection of over 1,000 specimens to be made. Samples were obtained from the whole length of the Andes mountains, not only in the more populous and easily accessible regions, but also in the wildest places far from human habitation, where no expeditions had collected previously.

The present work represents the results of nearly three years' study of the taxonomy and systematic classification of the Empire Potato Collection, using as a basis chiefly geographical, morphological and cytological criteria. In the U.S.S.R., Vavilov's complex taxonomic method was applied with signal success in elucidating the systematic relationships of

the potatoes collected by the Russian expeditions. Use was made, not only of the three criteria mentioned above, but also of genetical, biochemical and physiological data. For reasons already mentioned, it was not possible to employ all these methods in the present study; nevertheless the author ventures to believe that it is fairly complete in its essentials and will not need substantial alteration when the results of the tests for disease and frost resistance and for protein and vitamin-C content become available.

In order to clarify the subject of potato taxonomy, rather more than was necessary for a bare catalogue of the species encountered by the collectors has been included in the present work. There is indubitably a great need for a comprehensive treatise on potato taxonomy, especially on the problem of the wild species, which are described in scores of different periodicals in nearly every European language; moreover these publications are often inaccessible to both plant breeder and botanist. The present Bulletin cannot attempt to present a monographic treatment of the subject, since it would be rendered too cumbersome thereby. An outline of our present knowledge on the phylogeny and systematic relationships of wild and cultivated potatoes has, however, been embodied.

Bibliography on Insect Pest Resistance in Plants (with a Supplement on Resistance to Nematodes). Imperial Bureau of Plant Breeding and Genetics. Price 1s. 6d.

As plant breeding and genetics progress and the general standard of crop production and quality rises, the question of selection of types for their resistance to damage by insect pests advances more and more in the foreground in any program for the improvement of agricultural crops and other economic plants.

The sources drawn upon include publications from the British Commonwealth, the main European countries, U.S.A., various South American countries, U.S.S.R. and Japan. The bibliography with its supplement contains over 550 references, which are arranged according to subject.

A NEW JOURNAL

Proceedings of the Nutrition Society. Published by W. Heffer & Sons Limited, Cambridge, England. Price per volume (including 2 double numbers) 25s. Price of double numbers singly 15s.

This publication includes papers presented before the English and Scottish groups of *The Nutrition Society*. This organization was founded in 1941 for the purpose of the discussion and publication of papers presented by workers studying different aspects of the same problem in agricultural and medical institutions. The first issue (Vol. 1, Nos. 1 and 2), contains papers on: The Evaluation of Nutritional Status; Food Production and Distribution; Food Supplies in Relation to Human Needs (1) Requirements for Health and (2) Requirements in Terms of Food; Problems of Collective Feeding in War Time. The papers are by a number of leading English and Scottish workers.

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